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ELECTROMAGNETIC PULSE INVESTIGATION
OPERATION SNOW BALL

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Bell Telephone Laboratories, Inc.
On behalf of Western Electric Company, Inc.
222 Broadway, New York, N. Y.

Contract AF 29(601)-5991

TECHNICAL REPORT NO. AFWL-TR-65-61

August 1965

AIR FORCE WEAPONS LABORATORY
Research and Technology Division
Air Force Systems Command
Kirtland Air Force Base
New Mexico

AFWL-TR-65-61

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FOREWORD

This report was prepared by the Bell Telephone Laboratories, Inc., on behalf of the Western Electric Company, Inc., 222 Broadway, New York 14, N. Y., under Contract AF 29(601)-5991. The work was funded under DASA Project 5710, Subtask 04.097, Program Element 7.60.06.01.5. Inclusive dates of research were 18 January 1964 to 18 October 1964. The report was submitted 10 August 1965 by the AFWL Project Officer, Major Wallace D. Henderson (WLRP).

The authors wish to express their appreciation for the help and cooperation received from all of the participating AWRE group and particularly Messrs. S. D. Abercrombie, D. Dracott, F. Hill, and G. Roper for assistance in planning, and instrumenting the experiment.

The authors would also like to acknowledge the assistance of Major W. D. Henderson (AFWL/WLRPE) in arranging for and conducting discussions with the AWRE people at which the test results were correlated.

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This report has been reviewed and is approved.

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ABSTRACT

This report describes an experiment conducted during the summer of 1964 at the Suffield Experimental Station, Alberta, Canada, as a part of Operation Snow Ball (a 500-ton nonnuclear explosion). The purpose of the experiment was to determine whether nonnuclear detonations may be used to investigate the Electromagnetic Pulse (EMP) phenomena.

Sensors to detect electric and magnetic fields were included in Operation Snow Ball. Analysis of the data indicates that if magnetic fields were generated by the event, the fields were too small to be detected by the test instrumentation. However, the instrumentation did detect an electric field signal immediately following the detonation.

The results point out the need for either increased yields or increased detector sensitivity before further participation in nonnuclear events is warranted.

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SECTION I

INTRODUCTION

Project 6.1, Operation Snow Ball, was part of a joint United States/United Kingdom investigation of the Electromagnetic Pulse.

Project 6.1 and the experiments conducted, in Operation Snow Ball, by the group from the United Kingdom/Atomic Weapon Research Establishment (UK/AWRE) were closely coordinated and planned so that they would supplement and provide verification of results for each other.

This report describes an experiment conducted during the summer of 1964 at the Suffield Experimental Station, Alberta, Canada, as a part of Operation Snow Ball.

Operation Snow Ball was a 500-ton nonnuclear explosion primarily designed to obtain data on blast, shock and debris for hardening studies. However, arrangements were made to include this project (6.1), and an allied project[1] of the United Kingdom/Atomic Weapon Research Establishment (UK/AWRE).

1. Objective

The purpose of project 6.1 was to determine whether data could be obtained in nonnuclear events that would be of use in evaluating theoretical models that have been proposed describing the generation of an electromagnetic pulse (EMP) by either nuclear or nonnuclear explosions.

Specifically, this experiment was designed to obtain the following data:

a. The magnitude of the magnetic fields and the rate of change as a function of time and distance.

b. The magnitude and time history of the earth potential gradient as a function of distance.

c. The magnitude and time history of the vertical electric field.*

*The equipment for this experiment was furnished by Mr. S. D. Abercrombie and others of the United Kingdom/Atomic Weapon Research Establishment.

d. A time history of any change in the earth's electrostatic field.*

e. The magnitude and time history of currents induced in buried radial conductors.

2. Background

Considerable effort has been expended in order to obtain an understanding of the nuclear electromagnetic pulse (EMP) source mechanism. The results of previous tests and theoretical studies agree reasonably well. However, specifying protection criteria for future military systems or estimating the survivability of existing systems requires extrapolation of the available data to other yields and/or burst conditions. Consequently, obtaining data which helps define the source mechanism will increase the confidence in the required extrapolations.

3. Theory

One possible source for the low-frequency magnetic fields which have been observed in nuclear events is the exclusion and compression of the earth's magnetic field by the highly conducting plasma immediately surrounding the burst point. This mechanism, called the "Magnetic Bubble," has been discussed in unclassified documents by Dr. Colgate of the Lawrence Radiation Laboratory and others.[2,3,4] The bubble theory predicts a maximum field of a few gauss, with its amplitude and time rate of change determined by the conductivity (or temperature) and the rate of growth of the plasma. Since large yield non-nuclear detonations have fireball temperatures high enough to create a conducting plasma, then, according to the bubble theory, a low-frequency magnetic signal similar to that observed in nuclear events should be generated.

In addition to the "Magnetic Bubble Theory," there is experimental evidence from very-low-yield high explosive detonations (conducted by the University of Utah and others[5,6]) that electric field signals are generated. These electric field signals have at least two distinct components. The first of these is observed only when burst conditions are such that the explosive

*The equipment for this experiment was furnished by Mr. S. D. Abercrombie and others of the United Kingdom/Atomic Weapon Research Establishment.

products effectively short out the earth's electrostatic field. The maximum amplitude of this signal is on the order of 100 volts/meter with a rate of change proportional to the rate of growth and decay of the fireball.

The second component observed is higher in frequency and extremely random in nature. This randomness is observed both spatially around a single detonation and from shot-to-shot fired under identical conditions. A possible explanation for the generation of these "random" signals is: (1) charged metallic particles (from detonators, firing cables, etc.) are ejected at a high velocity and as they pass the sensors they induce signals or, (2) as the particles pass through the earth's field they act as small dipoles radiating signals at frequencies proportional to their physical dimensions.

Unfortunately, definitive measurements of this electric field phenomenon have been hampered in previous experiments due to small yields. Therefore, experiments were included in Project 6.1 (and the associated U.K. project[1]) to obtain a better understanding of the source mechanism.

SECTION II

PROCEDURE

1. Operations

The objective of Project 6.1 was to measure electrostatic and electromagnetic fields generated by the detonation of a large chemical explosion. To accomplish these measurements, three dynamic recording stations and a number of passive recording stations were used. In addition, a 5,000-foot length of No. 6 bare hard drawn copper wire was buried one foot below ground on a radial 49°30' east of true north starting 110 feet from GZ to measure any radial currents that might be generated.

One dynamic recording station (Station 1) was located along this wire at 360 feet from GZ and another (Station 2) was located along this same line 2,000 feet from GZ. The third station (Station 3) was located 360 feet from GZ in the Canadian sector diametrically opposite the radial wire. The experiment layout is shown on figure 1, while figure 2 is a detailed layout of the dynamic stations.

a. Electrostatic Field Measurements

Stations 1, 2, and 3 were instrumented to measure earth potential (E.P.).

Station 1 was equipped with a field mill to measure any change in the earth's electrostatic field.

Station 2 had a 2-meter antenna to measure the vertical electrical field.

b. Electromagnetic Field Measurements.

Stations 1, 2, and 3 were equipped to measure the time rate of change of magnetic flux density ($\dot{B}$) in two planes; vertical ($\dot{B}_v$) and tangential* ($\dot{B}_t$) at a depth of approximately two feet below the earth's surface. In

*This quantity is also referred to as the azimuthal component of the magnetic field and is represented by the symbol B_ϕ in other documents.

addition Stations 1 and 3 were equipped to measure $\dot{B}_v$ at a depth of 30 feet ($\dot{B}_{v(30')}$).

A number of passive devices called peak indicating magnetometers were used to measure tangential, vertical and radial peak magnetic fields. These devices were located along a free field line 23°30' east of true north as shown on figure 1.

c. Radial Current Measurement

Stations 1 and 2 measured currents induced in the radial wire. In addition, 22 passive peak current indicators were placed along the buried conductor as shown on figure 1.

d. Measurements Prior to Event

(1) Earth Resistivity Measurements

Measurements of the apparent resistivity of the soil (ρ) were made along the test line at locations shown on the map in figure 3. Some initial readings were made using two different types of equipment. The first, a Geophysical Instrument Company set, uses a potentiometer principle while the second set was a typical portable ground Megger. In both cases the resistivity measurements were made using the conventional 4-electrode method[7] irrespective of the instrument used.

Since there was no practical difference in the results obtained with these different instruments, the remaining portion of the readings were made with the Megger only. Electrode spacings and corresponding resistivity values are given in the table on figure 3.

The buried #6 ga. copper test conductor had already been placed by the time these resistivity measurements were made. To minimize mutual coupling, the test electrodes were arranged in a line perpendicular to the buried conductor with the exception of location #4 where the measuring electrodes were arranged parallel to and at a distance of only 1 foot separation from the buried conductor. No significant difference was noted however between the readings obtained with the parallel and perpendicular electrode configurations. Also the readings obtained at locations 15, 16, and 17 which are relatively remote from the buried conductor are essentially the same as those

obtained in proximity to the conductor. It is reasonable to conclude therefore that the presence of the #6 ga. buried conductor did not significantly modify the measurements obtained and consequently the data presented provide a valid indication of soil resistivity in the area investigated.

The soil resistivity measurements obtained by the conventional 4-electrode method indicate a resistivity near the surface ranging from about 80 to 100 ohm-meters. A practical check of these values was obtained by measuring the resistance-to-earth of a 3-foot ground rod and then computing the value of soil resistivity required to give a rod leakage resistance comparable to that obtained by measurement. In this way an indicated resistivity of 123 ohm-meters was obtained. The agreement between the soil resistivity values obtained in these two different ways is very good considering that we are dealing with a heterogeneous medium.

Based on the above-described measurements a shallow depth earth resistivity of 100 ohm-meters was assumed for all analytical computations.

(2) Surge Impedance Tests

Measurements were made of the impedance-to-earth of the #6 ga. buried test conductor when energized with an impulse voltage. Such information indicates how effectively the buried conductor contacts the soil.

A surge generator was set up as shown in figure 4. Impulse current was impressed on the buried conductor at an end point. Using a dual beam CRO, the current in the conductor and the voltage rise of the conductor at the point of energization were simultaneously recorded.

Measurements were made at a point about 3,000 feet from GZ where backfilling of the trench had stopped and the remaining conductor lay exposed in the trench. The conductor was cut at this point and the exposed section was pulled back from the test point a distance of about 100 feet to isolate it from the section under test. From a visual inspection, at the time these measurements were made, it appeared that in the buried section between the test point and GZ, the backfill had not been effectively compacted. This was especially true at the remote end from about 2,000 to 3,000 feet from GZ. The trench had not been completely backfilled and the fill was dry and very loosely

packed. The same type of impedance measurement was also made at the near end where the soil around the conductor was compacted to a greater degree. The oscillograms obtained in these tests are presented in figures 5 and 6. The impedance values are given in the following table:

Test Location	Time to Current Crest	Impedance-to-Earth at Time of Current Crest
End near GZ	40 μsec	9.4 Ω
End 3,000 ft. from GZ	40 μsec	18 Ω

Based on previous experience, impedances of this magnitude did not appear reasonable. Consequently, analytical calculations were made (using Sunde's method[8]) to verify the measurements. The results of the computations indicated that the effective earth resistivity, at the end near GZ, was approximately 300 ohm-meters and, at the end 3,000 feet from GZ, was about 1,000 ohm-meters.

The difference between the computed and measured value of earth resistivity is attributed to the poor contact between the buried conductor and the surrounding medium.

Based on excavations subsequent to the shot, it is the opinion of the authors that, in the interval between when the surge measurements were made and "shot time," the contact between the conductor and the soil was so improved (by vehicular traffic on the burial route) that there would have been little, if any, difference in the results of surge or earth resistivity tests if made immediately prior to the shot.

(3) Dynamic Tests of Tape Recording Systems

To provide an overall test of the circuitry and response of the tape recording systems, representative signals were employed to activate the measuring systems from transducers to recorders. Oscillograms were made of the test signals applied to a system and these were then compared with oscillograms obtained from readout of the tapes.

Figure 7 shows the arrangement of equipment employed to apply impulse current to a section of the buried radial conductor at a point where a pick-up device (split-core transformer) is installed. The impressed current wave and the corresponding wave obtained from readout of the tape at Station 2 are shown in figures 8, 9, 10, and 11. Tests were made of both a low- and a high-sensitivity channel. It may be noted that there is excellent agreement as to both magnitude and waveshape between the actual input wave and that obtained from readout of the tape. Similar tests were conducted at Station 1.

Another series of pre-event dynamic tests were made to check the operation of the $\dot{B}$ coils. The arrangement used to energize the $\dot{B}$ recording system is shown in figure 12.

For the testing of the $\dot{B}_v$ system (vertical field), the gaussing loop was placed flat on the ground directly above the buried pick-up loop. To test the $\dot{B}_t$ system (tangential field), the gaussing loop was placed in a vertical position with its lower edge touching the earth. The results of tests conducted at Station 2 are shown in figures 13, 14, 15, and 16. The oscillograms illustrate the differentiating action of the pickup coils.

2. Instrumentation

a. Dynamic Recording Stations

The recording equipment packages were installed in cylindrical steel (1/4 inch) containers 6 feet in diameter and 7 feet deep. These containers (figure 17), in addition to providing the required protection against blast and shock, also provide a degree of electromagnetic shielding for the instrumentation (recording) package.

These containers were buried in the earth so that the tops were level with the surface, figure 18. To insure a low-resistance electrical ground, the following methods were used. At stations 2 and 3, two holes, 1 foot in diameter and 5 feet deep were drilled in the floor of the excavated container hole. The holes were then filled with a slurry mixture.* Five-foot copper

*The slurry mixture used consisted of 25% salt, 25% bentonite and 50% native soil (dry volume) mixed with a sufficient volume of water to produce free pouring "mud." This was done to obtain a low ohmic resistance contact between the probes and the surrounding soil.

clad steel ground rods were installed in the holes and connected to the steel container using two #6 ga. insulated copper stranded wires. All connections were bolted and soldered to provide both mechanical strength and a good electrical connection, figure 19.

A different method was used to ground Station 1 due to the soil composition. The top layer consisted of approximately four feet of clay. From this point to the excavated depth of 10 feet, the composition was gravel and sand. Two 1-foot-diameter casings, 5 feet long, were set at the bottom of the hole and the area around the casings backfilled with damp clay. A slurry mixture was poured into the casings and the casings removed. Ground rods were inserted into the slurry mixture and connected to the container in the described manner. Three ground rods were driven horizontally into the surface layer of clay and connected in parallel to the station ground.

Each instrumentation package consisted of a magnetically and electrostatically shielded container (figure 18) in which recording, calibrating, sequence and timing equipment was mounted. At Stations 1 and 3 the recording equipment consisted of two battery-operated 14-channel tape recorders (figure 20). At Station 2, only one 14-channel battery operated recorder was used. Three of the five recorders used (one at each station) were AMPEX units (Model CP 100) which have a frequency response of dc to 200 kc at a tape speed of 60 inches per second (ips). The other two recorders used were PEMCO units (Model 110) also capable of recording from dc to approximately 200 kc at 60 ips tape speed.

All equipment, with the exception of the tape recorders, was designed and built for this project and is described in detail in sections 2b(1) and 3.

The operation of the recording package was controlled by hard wire timing signals. They were activated by the -5, -2, and/or -1 minute signals and were timed to pull tape from minus one to plus one minute. During the first and last 30 seconds of this 2-minute interval, the sequencing circuitry disconnected the transducers and applied previously set calibration signals

to the recorder inputs. In addition, both the voice countdown and the Zero Det.* signals were recorded to provide a time reference and assist in data analysis.

b. Dynamic Transducers

(1) Current Transformer

The method used to measure and record the magnitude and wave shape of the current pulse on the buried radial conductor was to derive a voltage input signal which was proportional to the current pulse. The transducer used for this measurement was a toroidal transformer with the following characteristics:

(a) Split-core design, capable of being opened so the device could be placed around the test cable to avoid opening the cable.

(b) A core opening sufficiently large to accept wires or cables up to diameters of 1.8 inches.

(c) High dielectric strength between the transformer windings and the test cable.

(d) Frequency response from about 10 cps to 200 kc when properly terminated.

(e) Current-handling ability in excess of 100 ka.

The design developed to meet these requirements employed a 500-turn secondary winding on a powdered permalloy toroidal core. The test line (cable) which is passed through the toroidal core constitutes a single turn primary.

The secondary winding was arranged in two halves (250 turns each). This winding arrangement allowed the device, after encapsulation in epoxy resin, to be cut into two C-shaped halves. A typical installation is shown in figure 21.

*Also referred to in other Snow Ball literature as the Det. Zero signal.

When the secondary windings are connected series aiding and terminated in a 3.03-ohm, noninductive resistor, figure 22A, the nominal output is approximately 1 volt with 160 amperes in the test line.

High dielectric strength (greater than 10 kv) to ground was provided by the epoxy encapsulation. An additional dielectric margin was provided by enclosing the transformer and termination in a plywood box.

The output from this transducer was transmitted to the recording equipment by a shielded twisted pair cable (W.E. Co. Type 754E Video Cable).

(2) Magnetic Field Transducers

Provision was made at all three stations to measure the time rate of change of magnetic flux density ($\dot{B}$). The technique employed was to measure the response induced in pickup loops by the varying magnetic flux. This loop (figure 22C), 0.878 meter in diameter, covering an area of 0.605 square meter, consisted of 10 turns of 20-ga. insulated wire, wound inside of an electrostatic shield. The shield was formed from a slotted copper tube and was electrically bonded to the transmission line shield.

The coil was resonant at 700 kc. A balanced matching pad of 1335 ohms (presented to the coil) to 135 ohms (presented to the WECo 754E video transmission cable) was selected to prevent integration of the signal over the recorder bandwidth. At each of the three stations, one of the above described coils was buried in the horizontal plane at a depth of 2 feet (figure 23) to measure $\dot{B}_v$. $\dot{B}_t$ was measured at each of the three stations with another of these coils buried vertically to the earth's surface and oriented so that the plane of the coil was radial to GZ. The center of the coil was at a depth of 2 feet (figure 26).

At the two 360-foot stations, an additional coil was buried in a horizontal plane at a depth of 30 feet. (Figures 24 and 25.) This coil, 0.152 meter in diameter, covering an area of 0.0182 square meter, consisted of 30 turns of 20-ga. insulated wire, wound inside of an electrostatic shield. The shield was formed from a slotted copper tube and was electrically bonded to the transmission line shield.

These coils were resonant at 900 kc. A balanced matching pad of 3415 ohms (presented to the coil) to 135 ohms (presented to the WECo 754E video transmission cable) was selected to prevent integration of the signal over the recorder bandwidth.

All coils were insulated from ground with rubber and vinyl plastic tape. The build-out pad was encapsulated in epoxy resin and all electrical connections were soldered and insulated with epoxy cement and vinyl tape.

(3) Earth Probes

The earth potential measuring probes consisted of 1/2-inch-diameter copper clad steel rods cut to a length of 1 meter, figure 22B. The rods, placed vertically in 12-inch-diameter holes, separated by 1 meter, were positioned with their centers 6 feet below the surface (figure 27). A slurry mixture* was used to backfill the holes to the tops of the rods. The remainder of the backfill was local soil.

The signal was brought to the measuring equipment via a matching resistance and 754E video pair cable.

(4) Field Mill

A field mill, furnished by Mr. S. D. Abercrombie and others of the United Kingdom/Atomic Weapon Research Establishment, was used to detect the time history of any change in the earth's electrostatic field.

The mill has two sets of stators, each of four sectors, under a grounded metal rotor. The geometry is such that the total area of stator exposed remains constant as the rotor revolves, while the exposed area of each individual stator varies in a triangular manner with time. For a given electric field, the charge induced on each stator is proportional to the exposed area, so the charge waveforms for the two stators are also triangular, but 180° out of phase. Each stator sees a virtual short circuit at the input to its amplifier; consequently, the input to the amplifier is the derivative of the charge induced on the stator plates.

*See note on Page 8.

The transistor amplifier has a gain of 100, and its output is integrated by a 0.1-uf capacitor in the collector circuit. The collector load for this transistor is a constant-current source. The voltage on this capacitor thus has the same waveshape as the stator charge, i.e., a triangular wave, whose peak amplitude is proportional to the applied electric field.

A separate amplifier is used for each of the two stators. The integrating capacitors are clamped to a -5.6-volt supply line via a trigger pulse derived from a pickup coil in the field mill. The outputs from the two integrating capacitors, consisting of antiphase triangular waveforms, are added in the output amplifier to give a steady dc output for a dc applied field.

This dc output is used to modulate the frequency of an oscillator whose basic frequency is approximately 108 kc.* The output of this oscillator, which is frequency modulated by the signal from the field mill is recorded directly onto magnetic tape.

(5) Vertical Antenna

A vertical whip antenna was used to detect the magnitude and time history of the vertical electric field. This equipment was also furnished by the United Kingdom/Atomic Weapon Research Establishment.

The installation consisted of (1) a 2-meter vertical whip antenna mounted on the steel bunker with a feed through insulator, and (2) a broad band amplifier mounted on the outside of the instrumentation package. The frequency spectrum covered is approximately 55 cps to 250 kc. A 10-kc signal was fed to the amplifier for calibration. The output of the broadband amplifier was transmitted to the recording package via a 72-ohm coaxial cable.

(6) Passive Instrumentation

In addition to the dynamic recording equipment just described, three types of passive peak indicating devices were employed. The first such device, Magnetic Links[9] provided a means of measuring both the peak amplitude

*The equipment used in the experiment had a center frequency of 114 kc.

and polarity of surge current flowing in a conductor. The second device, Peak Current Indicators[9] also records the peak amplitude of current in a conductor (figure 22D). Operating on a different principle, it provides a degree of redundancy. Although this latter device does not indicate polarity, it will resolve events of lower magnitude.

The third type is a free field device, referred to as a magnetometer (figure 22E), which is used to detect the peak magnitude of a transient free magnetic field. It is capable of recording the peak magnitude of a magnetic field as low as approximately 1 gauss.

As illustrated in figure 28, a magnetometer consists of two 1/4-inch stacks of 0.001-inch supermalloy laminations 6 inches long by 1/2 inch wide. One end of each stack has a 45° bevel on either side to form a 90° point. These stacks are placed in line point to point with 0.010-inch clearance between the points and potted in an epoxy compound. A length of 1/4-inch magnetic tape prerecorded at 7-1/2 ips with a 1000-cps sine wave signal is inserted through this 0.010-inch clearance hole in preparation for an event. When the magnetometer is exposed to a magnetic field, the peak flux density at the points of this device partially erases some of the prerecorded signal. The readout technique is very similar to that described in POR-2230 for Peak Current Indicators.

The maximum levels these passive devices are capable of measuring are given below:

a. Magnetic links - 10^5 amperes
b. Peak Current Indicators - 10^5 amperes
c. Magnetometers - ≥ 100 gauss

At each of the 11 peak current measuring stations (Stations 6.1.10 - 6.1.20) both a Magnetic Link and a Peak Current Indicator were installed.

A total of 23 magnetometers were installed at six locations (Stations 6.1.29 - 6.1.34). The magnetometers were oriented to measure tangential, vertical and radial magnetic fields at five stations. The radial field measurement was omitted at Station 6.1.33.

3. Recording Station Equipment and Calibration

Figure 29 is a simplified schematic for a typical transducer-to-recorder circuit. Shown in the schematic is the balanced transmission line from the transducer to the recording station, a balanced attenuator, a longitudinal suppression circuit, an isolation transformer, an unbalanced attenuator, an amplifier and/or zener protection circuit, and the tape recorder input.

The balanced attenuator is followed by a longitudinal suppression coil having a large mutual inductance and very low series inductance. This longitudinal coil is necessary because the isolation transformer could not provide the desired 60-db suppression of longitudinal signals up to 200 kc (the upper frequency limit of the isolation transformer for transverse signals). The balance potentiometer provides a low-impedance path to ground for the suppression coil and allows the system to be adjusted for minimum longitudinal noise signal. The combination of the longitudinal suppression coil, balance potentiometer and isolation transformer provided at least 60 db of longitudinal noise suppression from 20 cps to 200 kc.

The dynamic range and bandwidth objectives of the experiment were achieved by using up to four recorder channels for a single transducer. The use of four channels provides a dynamic range of 60 db and a bandwidth of dc to approximately 200 kc.

For channels where the predicted maximum signals were less than one volt at the isolation transformer secondary, a transistorized amplifier was used. A plug-in attenuator was used with each amplifier to adjust the gain.

The calibration of the tape recorder was accomplished by switching a 10-kc signal into the recorder at a known voltage level. This signal was switched in for a short time before and after the event by the timing and control unit. Thus, a known voltage was recorded on the magnetic tape which, in turn, is related to the transducer signal by a previously determined measurement of the insertion loss or gain of all elements between the transducers and the recorder. By recording the calibration signal both before and after zero time, any malfunctions or response changes in the tape recorder occasioned

by the test explosion were measured. Also, recorder drift or instability could be monitored by observing the pre- and post-calibration signals recorded on the tape.

Calibration of the station instrumentation was performed in the field after all the transducers were installed. Calibration included measurement of signal attenuation or gain, level of pre- and post-calibration signals, and alignment of the tape recorders. The level of the calibration signal was set to duplicate the highest predicted signal level for each channel. See tables 1 through 5 for signal level and channel assignments. The tape recorder input levels, bias, and carrier circuits were adjusted according to the manufacturer's instructions. See table 6 for frequency response and signal-to-noise ratio for the recorders used.

4. Passive Detector Calibration

The passive devices were calibrated in the laboratory for level sensitivity. An example of the methods used may be found in POR 2230, Appendix G.

While a laboratory calibration of the frequency response of these devices has not been conducted, the nature and construction of the devices is such that they will faithfully record the maximum amplitude of any frequency between dc and several megacycles.

TABLE 1

STATION #1 (360' FROM GZ) AMPEX RECORDER (U.S. SECTOR)

Channel Number	Type of Record Card	Quantity Measured	Transducer	Range Max.	Units of Measure	Value of Calibrate Signal
1	Direct	Voice Count	-	-	-	-
2	FM	I_c	Split Core Xformer	22	Amperes	44 A PtoP
3	Direct	I_c	✓	480	✓	960 A PtoP
4	Direct	$\dot{B}_v$	Loop 34.5" Dia.	0.14	Weber/Sq. Meter/ Second	$0.28 W/m^2/s$ PtoP
5	FM	$\dot{B}_v$	✓	4.0	✓	$8.0 W/m^2/s$ PtoP
6	Direct	$\dot{B}_T$	✓	0.14	✓	$0.28 W/m^2/s$ PtoP
7	FM	$\dot{B}_T$	✓	4.0	✓	$8.0 W/m^2/s$ PtoP
8	Direct	$\dot{B}_v$(30')	Loop 6"Dia.	6.4	✓	$12.8 W/m^2/s$ PtoP
9	FM	✓	✓	200	✓	$400 W/m^2/s$ PtoP
10	Direct	Electrostatic Field	Field Mill	1000	Volts/ Meter	151.7Kc = +1000V/m 115.5Kc = 0V/m 78.0Kc = -1000V/m
12	Direct	Earth Potential	2-1 Meter Rods 1 Meter Apart	8.0	Volts/ Meter	16V/m PtoP
13	FM	✓	✓	100	✓	200V/m PtoP
14	Direct	Zero Det	-	-	-	-

TABLE 2

STATION #1 (360' FROM GZ) PEMCO RECORDER (U.S. SECTOR)

Channel Number	Type of Record Card	Quantity Measured	Transducer	Range Max.	Units of Measure	Value of Calibrate Signal
1	Direct	Voice Count	-	-	-	-
2	Direct	I_c	Split Core Xformer	22	Amperes	44A PtoP
3	FM	I_c	✓	480	✓	960A PtoP
4	FM	$\dot{B}_v$	Loop 34.5" Dia.	0.14	Webers/Sq. Meter/Second	0.28W/m^2/s PtoP
5	Direct	$\dot{B}_v$	✓	4.0	✓	8.0 ✓ ✓
6	FM	$\dot{B}_T$	✓	0.14	✓	0.28 ✓ ✓
7	Direct	$\dot{B}_T$	✓	4.0	✓	8.0 ✓ ✓
8	FM	$\dot{B}_{v(30')}$	Loop 6"Dia.	6.4	✓	12.8 ✓ ✓
9	Direct	$\dot{B}_{v(30')}$	✓	200	✓	400 ✓ ✓
10	Direct	Electrostatic Field	Field Mill	1000	Volts/Meter	151.7Kc = +1000V/m 115.5Kc = 0V/m 78.0Kc = -1000V/m
12	FM	Earth Potential	2-1 Meter Rods 1 Meter Apart	8.0	Volts/Meter	16 V/m PtoP
13	Direct	Earth Potential	✓	100	✓	200 V/m PtoP
14	Direct	Zero Det	-	-	-	-

TABLE 3

STATION #2 (2000' FROM GZ) AMPEX RECORDER (U.S. SECTOR)

Channel Number	Type of Record Card	Quantity Measured	Transducer	Range Max.	Units of Measure	Value of Calibrate Signal
1	Direct	Voice Count	-	-	-	-
2	FM	I_c	Split Core Xformer	22	Amperes	44 A PtoP
3	Direct	I_c	✓	22	✓	44 ✓ ✓
4	FM	I_c	✓	480	✓	960 ✓ ✓
5	Direct	I_c	✓	480	✓	960 ✓ ✓
6	FM	$\dot{B}_V$	Loop 34.5 Dia.	0.14	Weber/Sq. Meter/ Second	$0.28 W/m^2/s$ PtoP
7	Direct	$\dot{B}_V$	✓	0.14	✓	0.28 ✓ ✓
8	Direct	$\dot{B}_V$	✓	4.0	✓	8.0 ✓ ✓
9	Direct	$\dot{B}_T$	✓	0.14	✓	0.28 ✓ ✓
11	Direct	Earth Potential	2-1 Meter Probes 1 Meter Apart	0.4	Volts/ Meter	0.8 V/m PtoP
12	Direct	✓	✓	12	✓	24 V/m PtoP
13	Direct	Electrostatic Field	2 Meter Aerial		Volts/ Meter	2 Volts PtoP UK Electronics
14	Direct	Zero Det	-	-	-	

TABLE 4

STATION #3 (360' FROM GZ) AMPEX RECORDER (CANADIAN SECTOR)

Channel Number	Type of Record Card	Quantity Measured	Transducer	Range Max.	Units of Measure	Value of Calibrate Signal
1	Direct	Voice Count	-	-	-	-
2	FM	$\dot{B}_{v}(30')$	Loop 6"Dia.	6.4	Weber/Sq. Meter/ Second	12.8 $W/m^2/s$ PtoP
3	Direct	✓	✓	200	✓	400 ✓ ✓
4	Direct	$\dot{B}_{v}$	Loop 34.5" Dia.	0.14	✓	0.28 ✓ ✓
5	FM	$\dot{B}_{v}$	✓	4.0	✓	8.0 ✓ ✓
6	Direct	$\dot{B}_{T}$	✓	0.14	✓	0.28 ✓ ✓
7	FM	$\dot{B}_{T}$	✓	4.0	✓	8.0 ✓ ✓
8	Direct	Earth Potential	2-1 Meter Rods 1 Meter Apart	8.0	Volts/ Meter	16 V/m PtoP
9	FM	✓	✓	100	✓	200 ✓ ✓
14	Direct	Zero Det	-	-	-	-

Table 5

STATION #3 (360' FROM GZ) PEMCO RECORDER (CANADIAN SECTOR)

Channel Number	Type of Record Card	Quantity Measured	Transducer	Range Max.	Units of Measure	Value of Calibrate Signal
1	Direct	Voice Count	-			
2	Direct	$\dot{B}_v(30')$	Loop 6" Dia.	6.4	Webers/Sq. Meter/ Second	12.8 $W/m^2/s$ PtoP
3	FM	✓	✓	200	✓	400 ✓ ✓
4	FM	$\dot{B}_v$	Loop 34.5" Dia.	0.14	✓	0.28 ✓ ✓
5	Direct	✓	✓	4.0	✓	8.0 ✓ ✓
6	FM	$\dot{B}_T$	✓	0.14	✓	0.28 ✓ ✓
7	Direct	✓	✓	4.0	✓	8.0 ✓ ✓
8	FM	Earth Potential	2-1 Meter Rods 1 Meter Apart	8.0	Volts/ Meter	16.0 V/m ✓
9	Direct	✓	✓	100	✓	200 V/m ✓
14	Direct	Zero Det	-	-	-	- - -

TABLE 6

MAGNETIC TAPE RECORDER SPECIFICATIONS

Model	No. of Tracks	Freq. Response (at 60 ips)		Signal-to-Noise Ratio	
		FM Record	Direct Record	FM Record	Direct Record
Ampex CP-100	14	DC to 20 kc	300 cps to 200 kc	44 db	30 db
Pemco 110	14	DC to 10 kc	300 cps to 150 kc	40 db	27 db

SECTION III

RESULTS

The results which follow were correlated with those of the UK/AWRE at a meeting at their facility in Aldermaston, England. At this meeting all apparent anomalies in the results of the two experiments were resolved.

The results of the British project are reported in a separate document.[1]

1. Dynamic Measurements

All recorders at all stations operated successfully and were recovered. The records indicate that if magnetic fields were generated by the event, the fields were too small to be detected. The records further indicate that there was an electric field signal immediately following the detonation.

a. Analysis Techniques

The data tapes for all three stations were analyzed by two techniques.

(1) CRO Analysis

The test tapes were played back on an Ampex CP 100 in real time at 60 ips and observed on a cathode ray oscilloscope (CRO), Tektronixs Inc., Type 551. Using the Zero Det. signal as a trigger for a delay generator and the output of the delay generator to trigger the CRO, any point in time following the Zero Det. may be examined. By using a CRO sweep time of 1.0 millisecond per centimeter, a 10.0-millisecond time segment can be examined and recorded photographically. The delay generator was adjusted in approximately 9.0-millisecond increments to provide some overlap for each successive time segment. By using a faster CRO sweep time (i.e., 1 usec) and adjusting the delay generator accordingly a particular time segment can be examined in detail. Use of a slow CRO sweep time (i.e., 100 milliseconds) permits a broad look at the data. The period from Zero Det. to plus 100 milliseconds was examined for Stations 1 and 3. Station 2 data were examined to approximately plus 2.0 seconds.

(2) Visicorder Analysis

The data tapes (which were recorded at 60 ips) were played back at 7-1/2 ips and then recorded on a Minneapolis Honeywell Visicorder Model 1012

Oscillograph. The Visicorder makes use of moving coil galvonometers having an upper frequency response of 8.0 kc. Because of the reduction in tape playback speed of 8:1, the effective bandwidth of the Visicorder records is dc to 64 kc.

Visicorder records were made with the recording paper traveling at 40 inches per second. Timing lines were applied every 10 milliseconds as the paper passes through the machine. Because of the 8:1 reduction in playback speed these timing lines are spaced every 1.25 milliseconds in real time.

The galvanometer amplifiers were adjusted to produce a deviation of 8 divisions peak to peak as the 10-kc calibrate signal of the m[illegible]tic tape was played. (The Zero Det., Chan. 14, was adjusted for half gair [illegible]revent excessive galvanometer deviation on the large signal.)

b. Analysis Results

(1) CRO Technique*

(a) Station 1

1 At approximately 51.1 ms (roughly ground shock arrival time**) signals were observed on the $\dot{B}_{v(30')}$ and $\dot{B}_v$ channels. These signals were 0.16 webers/square meter/second (W/m^2/s) peak to peak for the $\dot{B}_{v(30')}$ channel, see figure 30, and 0.0035 W/m^2/s peak to peak for the $\dot{B}_v$ channel (figure 31.). These signals are of a magnitude such that they could have been produced by transducer motion at ground shock arrival.

*As previously noted, data were recorded in two modes (Direct and FM) and extremely low level signals were expected. Since the signal levels were small (as predicted by Drs. Wesley, Wouters, and others) and due to the lower signal to noise ratio of the Direct channels (30 db vs. 40 db for FM) it was necessary to insert bandwidth limiting filters (Spencer-Kennedy Laboratories, Inc. Model 302) in the Direct Channel playback equipment. As a consequence of the limited useful bandwidth (dc to 20 kc) it is possible that extremely low level (or extremely high frequency) signals were generated but were obscured by (normal) recording equipment noise.

**Data obtained from the Suffield Experimental Station indicate that ground shock arrival time at 360 feet from GZ was approximately 50 milliseconds.

2 At approximately 71.9 milliseconds (roughly air-blast arrival time*) signals were observed on the $\dot{B}_{v(30')}$, $\dot{B}_v$ and I_c channels. These signals were as follows:

$\dot{B}_{v(30')}$ - Figures 32 and 33 show signals of 0.23 $W/m^2/sec$ peak to peak and 0.45 $W/m^2/sec$ peak to peak respectively. The difference in wave shapes is due to the frequency response of the recorder channels. Figure 32, a direct channel, has a response of 300 cps to 20 kc (due to filtering required to remove noise) while figure 33, an FM channel, has a frequency response from dc to 10 kc. The repetitive pulses seen in figure 32 are internally generated by the playback equipment. This is illustrated on figures 34 and 35 which were made with playback electronics ON but with the tape stationary.

$\dot{B}_v$ - Figures 36 and 37 show signals of 0.004 $W/m^2/sec$ peak to peak and 0.008 $W/m^2/sec$ peak to peak respectively. Again the difference in wave shapes is due to the frequency response of the recorder channels. The repetitive pulses seen on figure 36 are due to the playback equipment.

I_c - Figures 38 and 39 show signals of 1.3 amperes peak to peak and 0.3 ampere peak to peak respectively. Wave shape differences are due to the frequency response of the recorder channels. Figure 40 shows a signal of 12 amperes peak to peak which is inconsistent with figures 38 and 39. Figure 40 is included to show time correlation. The sensitivity of the channel shown on figure 40 is low and the small signal (as indicated by figures 38 and 39) is below the linear dynamic range; therefore, the magnitude is invalid. The signals described above are of a magnitude that could have been produced by transducer motion due to the air blast.

3 At approximately 68.5 milliseconds, the field mill output goes off scale. Figures 41 and 42 show that a definite negative field appeared just prior to destruction. It is believed that this field was caused by the

*Data obtained from the Suffield Experimental Station indicate that air-blast arrival time at 360 feet from GZ was approximately 68 milliseconds.

dust cloud which immediately preceded the air blast. These data are consistent with those observed by the U.K. about 300 feet from GZ in the U.K. sector (approximately opposite Station 1).

(b) Station 3 (360 feet from GZ in Canadian Sector)

1 No valid signals were observed.

2 It was found that the Pemco Recorder ran slow by about 20 percent.

(c) Station 2 (2,000 feet from GZ in U.S. Sector)

No signals were observed at this station.

(d) Stations 1 and 3

1 At approximately 75 milliseconds (corresponding to air-blast arrival time), the Zero Det. signal cable produced an output which exceeded the actual Zero Det. signal at Station 3 and was about equal to the Zero Det. signal at Station 1. Figure 43 shows the Zero Det. signal at Station 3 while figure 44 shows the spurious signal. It will be noted that the Zero Det. signal consists of a number of pulses. This was expected and was observed during dry runs prior to the actual event. Figure 45 shows the spurious signal. These spurious signals are believed to have been produced by cable whipping and destruction of various line amplifiers by the air blast. The above signals are exhibited as further evidence of air-blast arrival time and because the large spurious signal at Station 3 caused some inter-channel crosstalk.

2 There is evidence of crosstalk between heads in the recorders at both Station 1 and 3. The recording heads are arranged in two stacks, even-numbered channels in one stack and odd-numbered channels in the other. This is true of both the Ampex and Pemco recorders.

At Station 1 the field mill was assigned channel 10 on both Ampex and Pemco recorders. Crosstalk was observed on even-numbered channels following the destruction of the field mill.

At Station 3 the Zero Det. was assigned channel 14 on both Ampex and Pemco recorders. Crosstalk was observed on even-numbered channels during the large output from the Zero Det. cable mentioned in 1 above.

(2) Visicorder Technique

The visicorder records shown as figure 47 and figure 48 were made from the Ampex tapes at Stations 1 and 3 respectively. The calibration signals are shown to the left of the figures. The time between the end of the pre-calibration signal and the Zero Det. (30 seconds) is not shown. The signal traces start at about -3 milliseconds and continue to +85 milliseconds. The channel number, type of channel and quantity measured is indicated on each trace.

The Station 1 record (figure 47) shows signals at about 72 milliseconds on channels 2 (I_c), 4 ($\dot{B}_v$) and 8 ($\dot{B}_{v(30')}$). These signals are circled and lettered A, B, and C respectively on the record. These signals were also observed by the CRO technique described in the previous section. Figures 39, 36, and 32 correspond to signals lettered A, B, and C respectively on figure 47.

The large field mill signal appears on Channel 10 (see figures 41 and 42 for corresponding CRO data). The crosstalk resulting from this large signal may be observed on the channel 2, 4, 6 and 8 traces of figure 47.

Figure 48, the Station 3 record, shows no discernible data signals. At about 75 milliseconds the large spurious signal may be observed on the channel 14 trace (see figure 43 for the corresponding CRO data). The resulting crosstalk may be observed on the channel 2, 4, 6, and 8 traces.

Both visicorder records indicate cyclic background noise on direct channels both before and after Zero Det. As was the case with CRO analysis the small signals recorded are difficult to observe because of this noise.

c. Data Correlation

The data obtained shows good correlation as evidenced by the examples given below:

(a) Figure 30 ($\dot{B}_{v(30')}$) and figure 31 ($\dot{B}_v$)

1 Wave shape is identical.

2 Time and duration of signals are the same.

3 $\dot{B}_{v(30')}$ signal is greater than $\dot{B}_v$. The $\dot{B}_{v(30')}$ transducer was freer to move and hence the shock wave should produce a larger signal.

(b) Figure 32 ($\dot{B}_{v(30')}$) and figure 33 ($\dot{B}_{v(30')}$)

1 Time and duration of signals are the same.

2 Difference in signal levels and wave shapes are consistent with the pass bands of the recording channels used.

(c) Figure 36 ($\dot{B}_v$) and figure 37 ($\dot{B}_v$)

1 Time and duration of signals are the same.

2 Difference in signal levels and wave shapes are consistent with the pass bands of the recording channels used.

(d) Figure 32 $\dot{B}_{v(30')}$ and figure 36 $\dot{B}_v$

1 Wave shape identical.

2 Time and duration of signals are the same.

3 See example A3.

(e) Figure 33 ($\dot{B}_{v(30')}$) and figure 37 $\dot{B}_v$

1 Wave shape identical.

2 Time and duration of signals are the same.

3 See A3.

(f) Figure 38 (I_c) and figure 39 (I_c)

1 Time and duration of signals are the same.

2 Difference in signal levels and wave shapes are consistent with the pass bands of the recording channels used.

(g) Figure 41 (field mill) and figure 42 (field mill)

1 Wave shapes similar.

2 Time and duration the same.

3 Signal levels equal.

4 U.K. made similar observations.

2. Passive Detector Results

The results obtained by the passive peak current indicators and magnetometers further substantiate the results obtained by the dynamic recordings. The results obtained by these devices are as follows:

a. Conductor Current

The magnetic links did not show any indication on the readout meter. Although about 500 peak amperes in a conductor is required to give a reading capable of specific analysis, a current of just a few amperes will produce a slight movement of the sensitive readout meter. Since in no case was any motion observed, it must be concluded that if any current were present in the test conductor, it had to be of very low magnitude. This was also confirmed by the other peak current devices. These employed a prerecorded tape and no definite discontinuity in the envelope could be detected.

b. Magnetometers

One magnetometer indicated a possible signal of 0.75 gauss ± 25 percent.

It is possible to produce a signal of this magnitude by mechanical damage to the device in the process of loading.

Since the device indicating a possible signal was located 460 feet from GZ, and no signals were observed on devices located closer to GZ, it seems highly unlikely that the observed signal is valid.

SECTION IV

CONCLUSIONS

The results of this test indicate that the degree of ionization that can be achieved by a nonnuclear detonation is either:

a. Insufficient to exclude and/or compress the earth's magnetic field, or

b. When the ionization is suffciently high to generate a magnetic bubble its size is so small that the effect of the bubble cannot be detected at any appreciable distance (100-200 feet).

SECTION V

RECOMMENDATIONS

Continued study of the EMP phenomena using nonnuclear explosives does not appear to be warranted unless:

a. Arrangements can be made to completely circle GZ with a conductor so as to improve the coupling, or

b. The yield is increased by at least one order of magnitude over that of Snow Ball.

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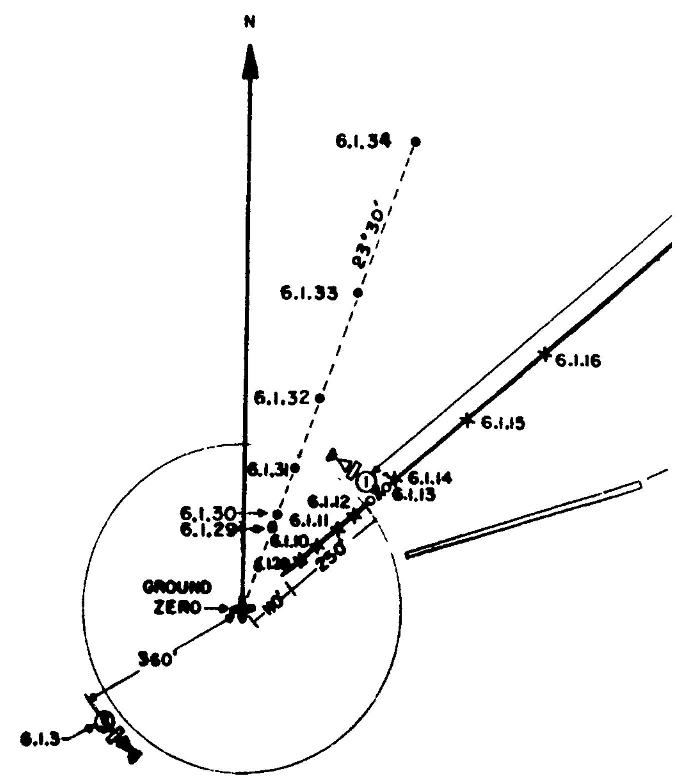
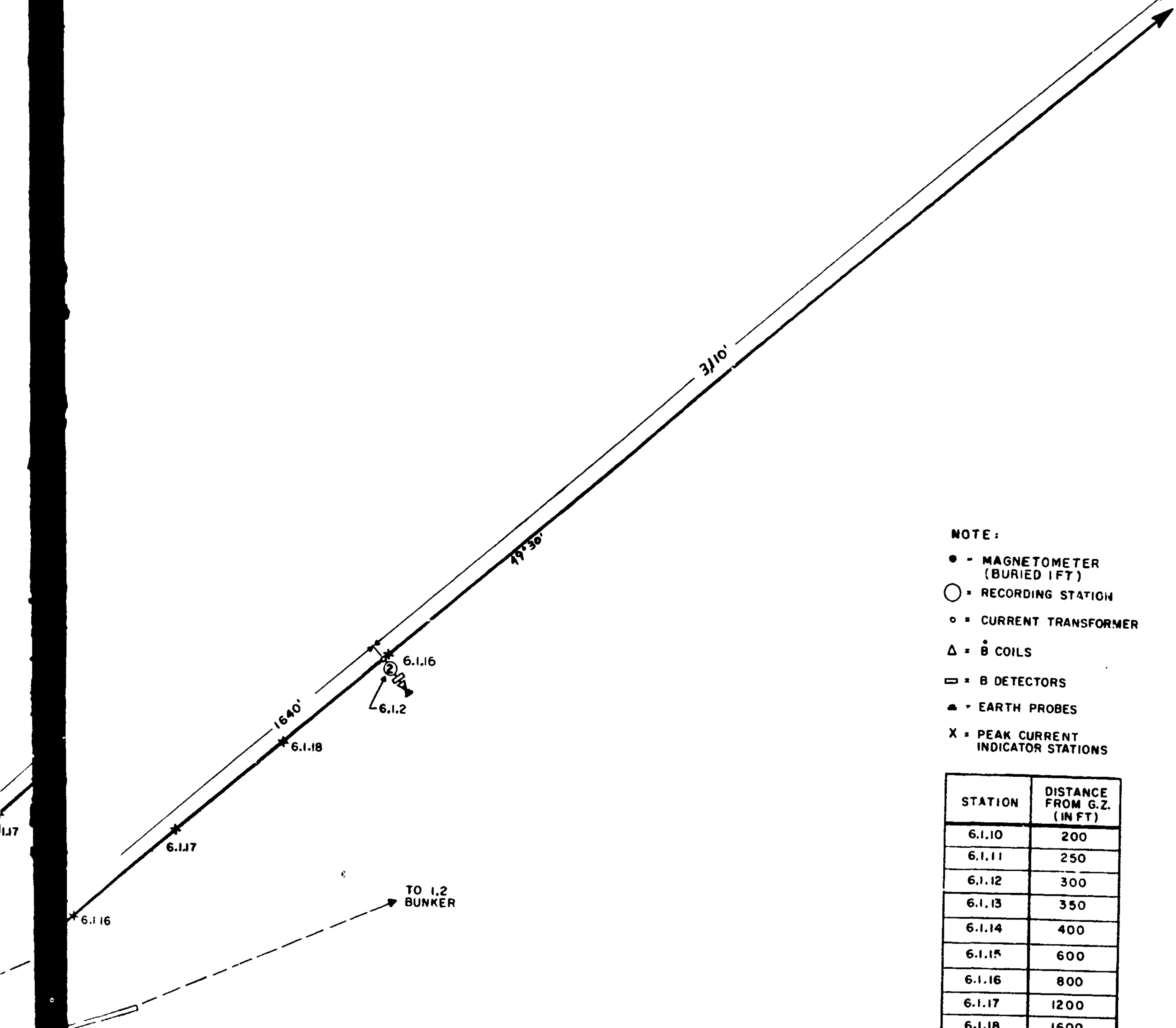
*For a complete Bibliography see "Bibliography On Ground Resistance and Potential Gradient Measurements," Paper No. 60 - 1, AIEE Transactions, February 1960.


N
6.1.34
23°30'
6.1.33
6.1.32
6.1.31
6.1.30
6.1.29
6.1.16
6.1.15
6.1.14
6.1.13
6.1.12
6.1.11
6.1.10
GROUND
ZERO
360'
6.1.3



NOTE:

- ● - MAGNETOMETER (BURIED 1 FT)
- ◯ = RECORDING STATION
- o = CURRENT TRANSFORMER
- Δ = $\dot{B}$ COILS
- ▭ = B DETECTORS
- ▲ - EARTH PROBES
- X = PEAK CURRENT INDICATOR STATIONS

STATION	DISTANCE FROM G.Z. (IN FT)
6.1.10	200
6.1.11	250
6.1.12	300
6.1.13	350
6.1.14	400
6.1.15	600
6.1.16	800
6.1.17	1200
6.1.18	1600
6.1.19	2000
6.1.20	175
6.1.29	175
6.1.30	200
6.1.31	300
6.1.32	450
6.1.33	675
6.1.34	1000

FIG. 1
BURIED CONDUCTORS & STATION LAYOUT
PROJECT 6.1

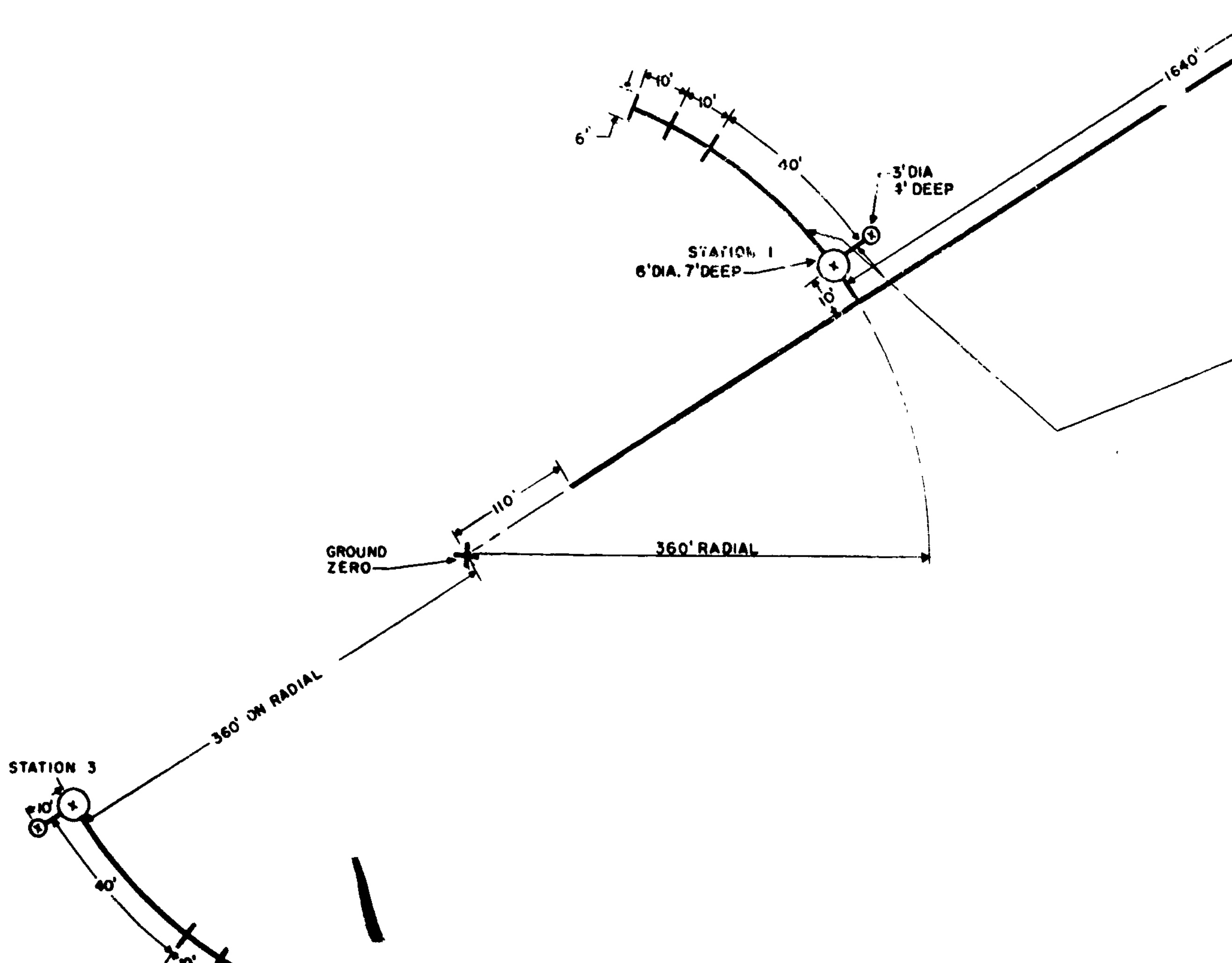
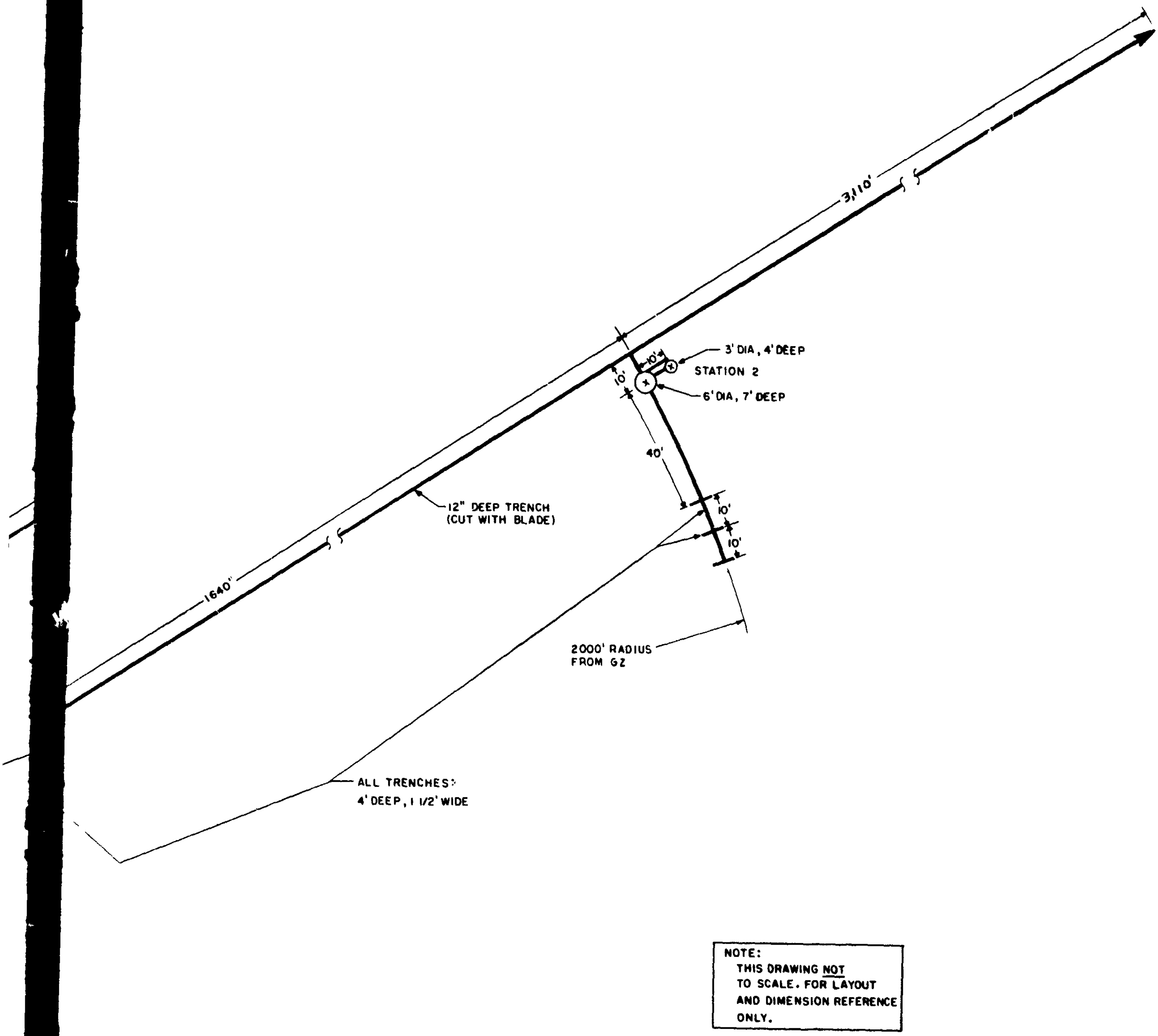


FIG. 2
STATION & TREN
PROJECT



2

FIG. 2
STATION & TRENCH LAYOUT
PROJECT 6.1

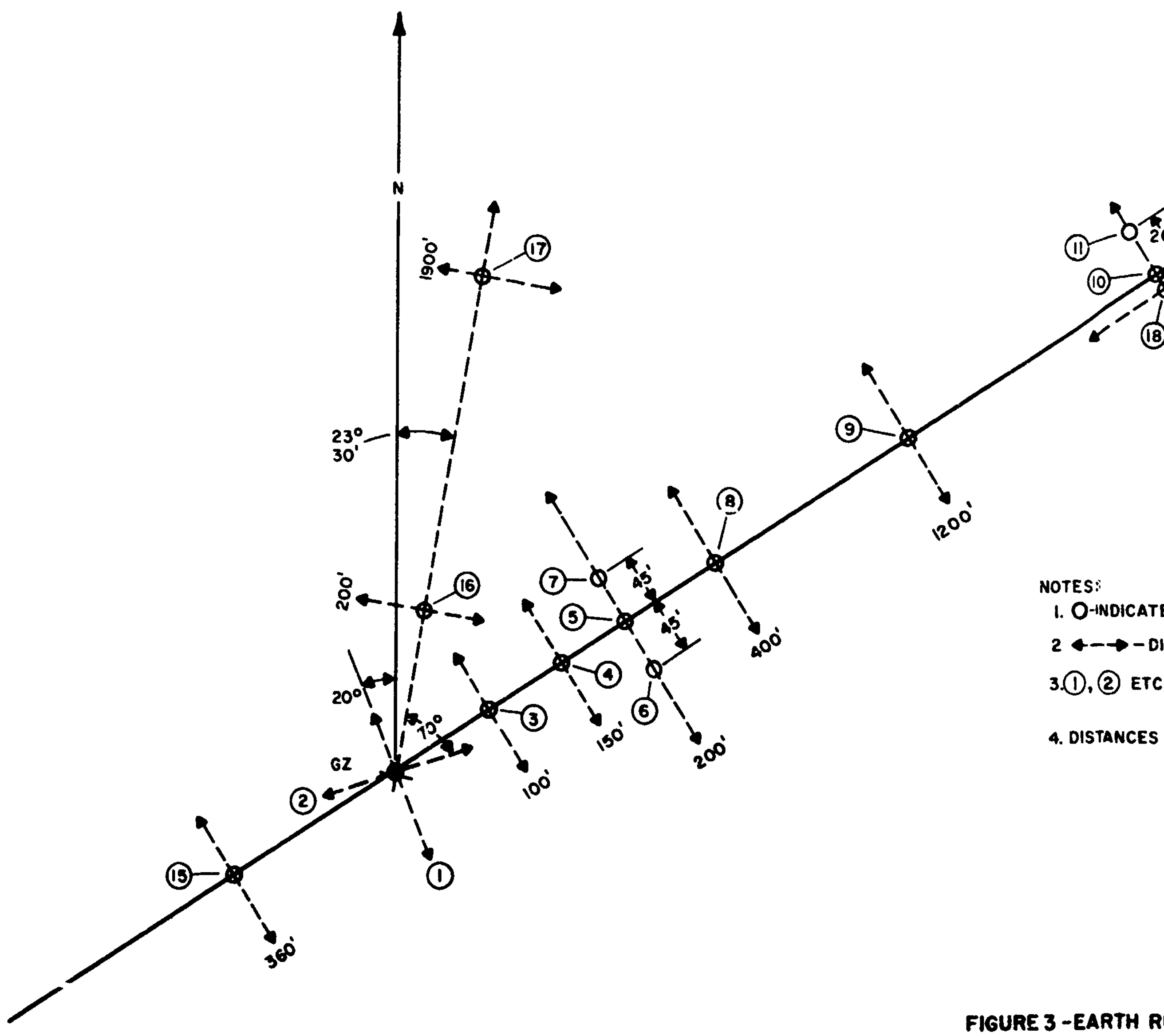
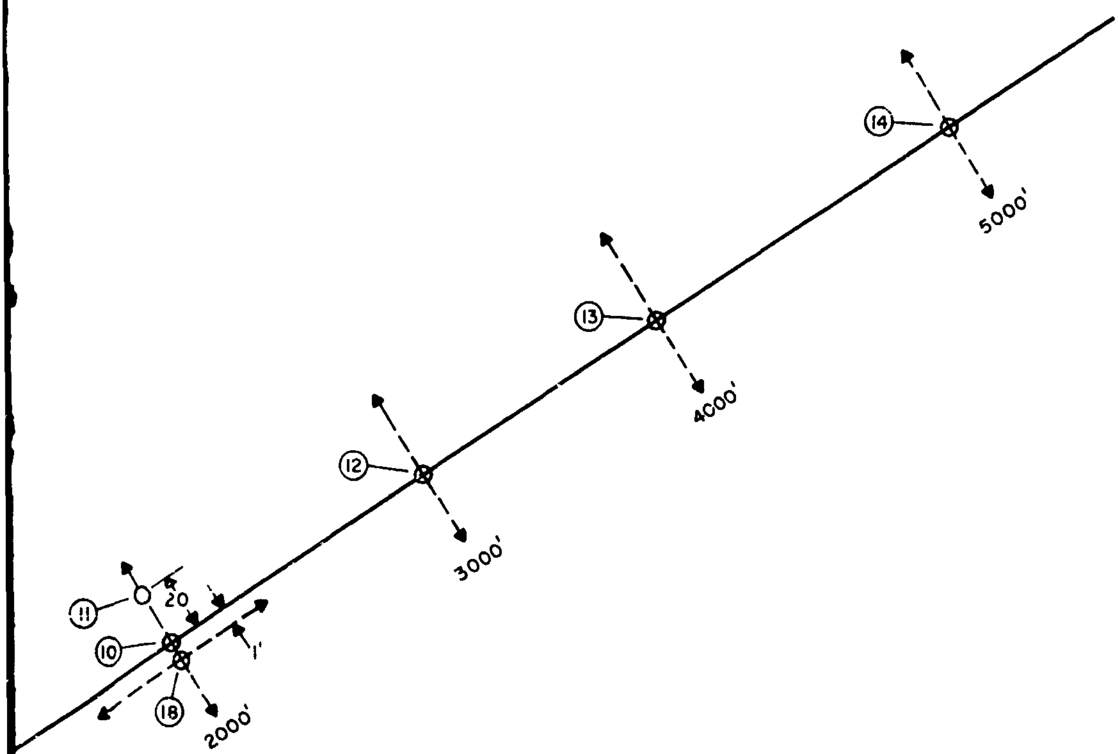


FIGURE 3 -EARTH R



NOTES:

1. O-INDICATES LOCATION OF MEASURING INSTRUMENT
2. ◆--◆ - DIRECTION PROBES WERE PLACED
3. ①, ② ETC - MEASURING LOCATION NUMBERS WHICH KEY WITH DATA SHEET #
4. DISTANCES IN FEET FROM GZ

RE 3 -EARTH RESISTIVITY MEASURING LOCATIONS

MEASUREMENTS OF APPARENT SOIL RESISTIVITY

MEASURING LOCATION NUMBER	ELECTRODE SPACING IN FEET					
	1	3	9	27	81	243
	APPARENT RESISTIVITY IN OHM-METERS					
1	23	32	41	57	37	19
2	28	40	42	67	70	47
3	25	20	11	34	64	33
5	43	55	44	122	101	23
6	29	37	76	137	-	-
7	25	37	30	55	-	-
8	29	37	67	110	51	-
9	67	58	44	35	23	47
10	56	78	31	17	25	-
11	96	97	45	20	-	-
12	119	63	34	35	31	37
13	155	70	27	31	23	56
14	186	85	67	106	155	46
15	47	53	62	101	78	19
16	38	42	29	66	96	23
17	79	22	13	16	33	-
18	92	180	170	57	37	51

MEASURING LOCATION NUMBER	ELECTRODE SPACING IN FEET					
	2	5	10	20	40	
	APPARENT RESISTIVITY IN OHM-METERS					
4	46	43	42	71	100	

2

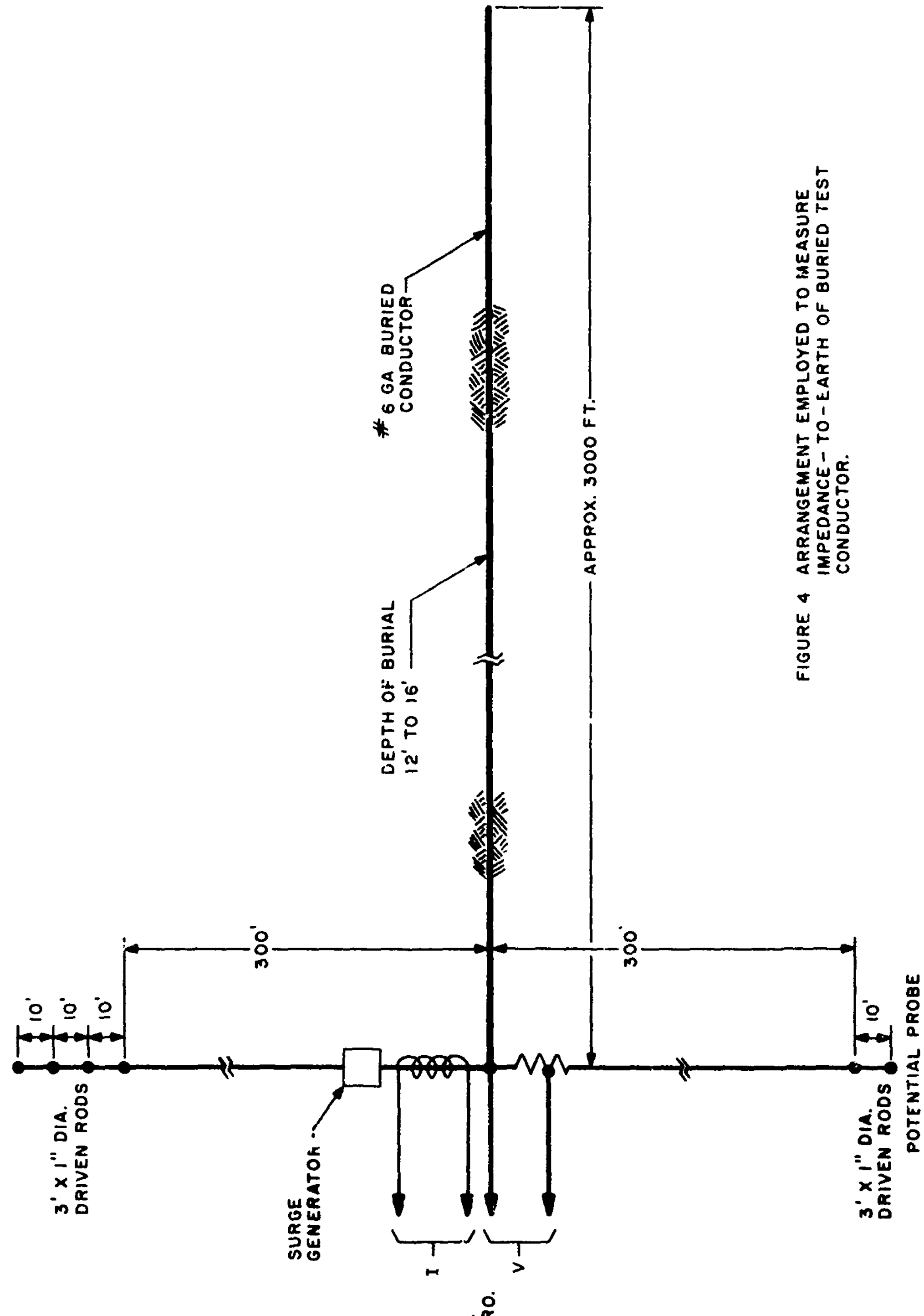


FIGURE 4 ARRANGEMENT EMPLOYED TO MEASURE IMPEDANCE - TO - EARTH OF BURIED TEST CONDUCTOR.

IMPEDANCE-TO-EARTH OF BURIED RADIAL TEST CONDUCTOR

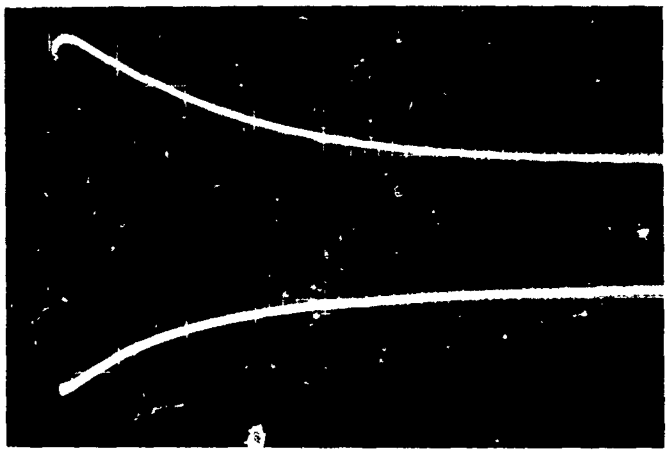


FIGURE 5

Impedance Measurement at End of Buried Conductor Near GZ

Calibration:

Upper Curve $-I_c = 50$ Amp/cm

Lower Curve $- V = 500$ V/cm

$t = 200\mu$ sec/cm

$I_c = 1.7 \times 50 = 85$ Amps

$V = 1.4 \times 500 = 700$ Volts

$Z = \frac{700}{85} = 8.2\ \Omega$

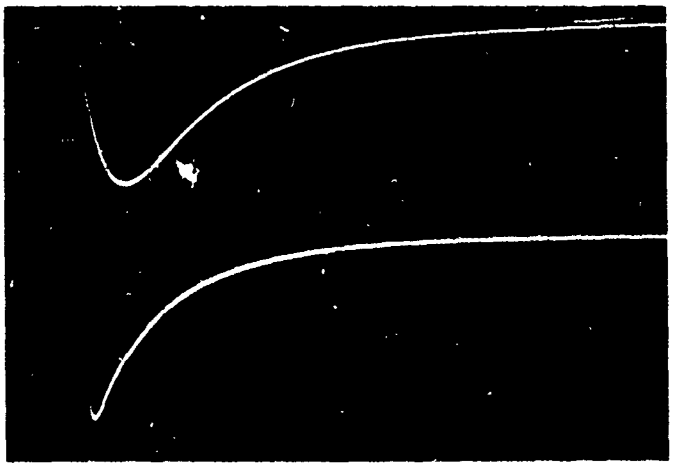


FIGURE 6

Impedance Measurement at End of Buried Conductor 3000 ft from GZ.

Calibration:

Upper Curve $I_c = 20$ Amps/cm

Lower Curve $V = 500$ V/cm

$t = 50\mu$ sec/cm

$I_c = 2.2 \times 20 = 44$ Amps

$V = 1.6 \times 500 = 800$

$Z = \frac{800}{44} \cong 18\ \Omega$

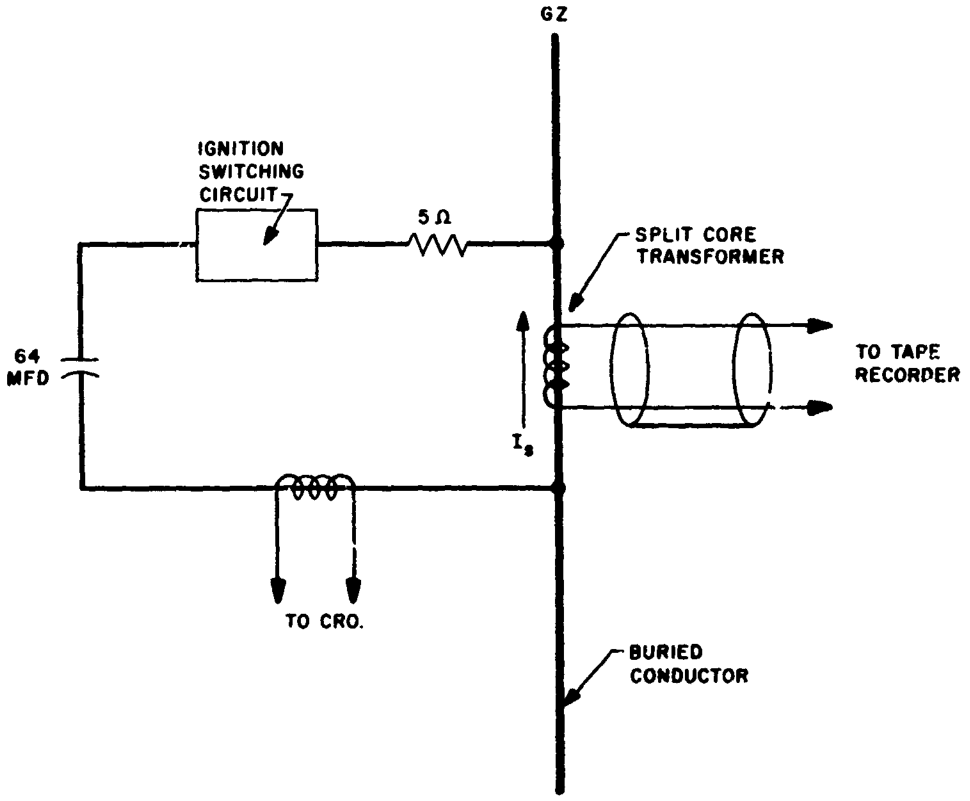


FIGURE 7. ARRANGEMENT OF EQUIPMENT FOR PRODUCING IMPULSE CURRENT IN BURIED CONDUCTOR

RESULTS OF SURGE CURRENT TESTS AT STATION NO. 2

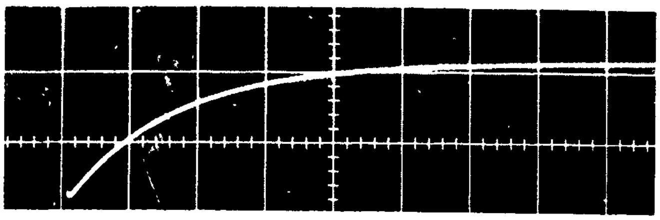


FIGURE 8

Test Current, (I_s) in Buried Conductor
Calibration
20. V/cm, t = 200μ sec/cm
Generator Charge 2000 V
$I_c = \frac{20}{1}$ = 200 Amps/cm, = 1.9 x 200 = 380 Amps

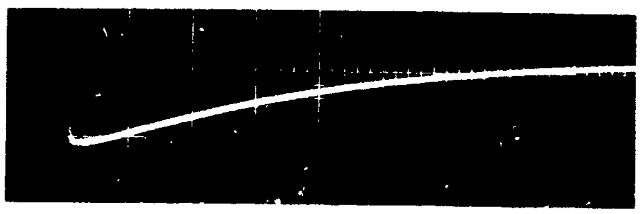


FIGURE 9

Readout from Channel 5 of Recorder
Calibration.
2.0 V/cm, t = 200μ sec/cm
I_c = 160 x 1.1 x 2.0 = 396 Amps

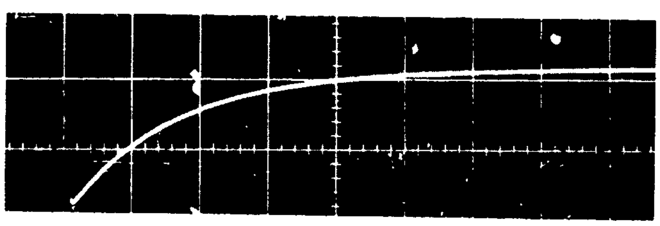


FIGURE 10

Test Current, (I_c) in Buried Conductor
Calibration
5.0 V/cm, t = 200μ sec/cm
Generator Charge = 500 V
$I_c = \frac{5.0}{.1}$ = 50 Amps/cm
= 1.9 x 50 = 95 Amps

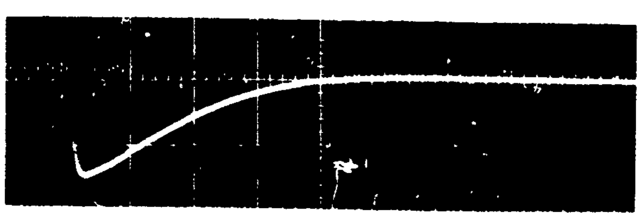


FIGURE 11

Readout from Recorder Tape – Channel No 3
Calibration
5.0 V/cm, t = 200μ sec/cm
$I_c = \frac{5.0}{0.9}$ Amps/cm
= 1.5 x 55.5 $\cong$ 83 Amps

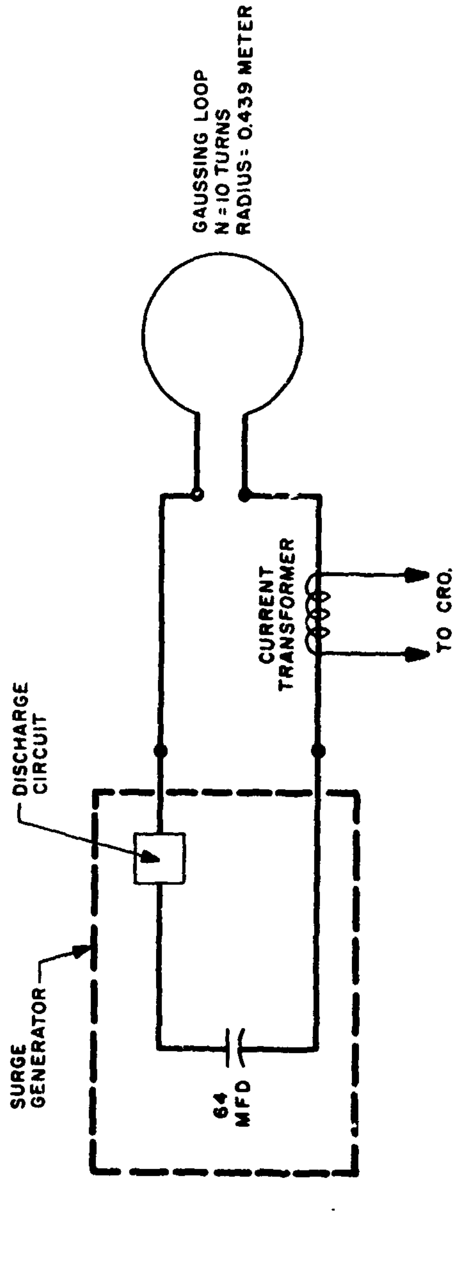


FIGURE 12. ARRANGEMENT FOR GENERATING A MAGNETIC FIELD TO TEST $\dot{B}$ RECORDING SYSTEM

RESULTS OF SURGE TESTS OF $\dot{B}$ RECORDING SYSTEM AT STATION NO. 2

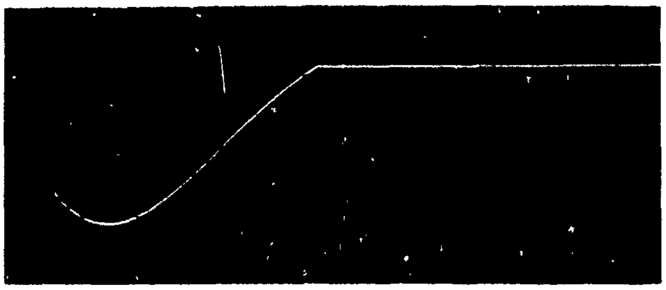


FIGURE 13

Current (I_L) into Gaussing Loop-Orientation for Vertical Field

Calibration:

$i = \frac{10\ V/cm}{0.1} = 100$ Amps/cm

$t = 100\ \mu$ sec/cm

$I_L = 2.2 \times 100 = 220$ Amps

FIGURE 14

Output of $\dot{B}_V$ Coil with Current in Gaussing Loop shown in Fig 13

Calibration:

$V = 2.0$ V/cm

Initial Voltage Peak = $1.1 \times 2.0 = 2.2$ Volts

FIGURE 15

Current in Gaussing Loop-Orientation for Tangential Field

Calibration:

$I_L = 200$ A/cm

$= 2.9 \times 200 = 580$ Amps

$t = 100\ \mu$ sec/cm

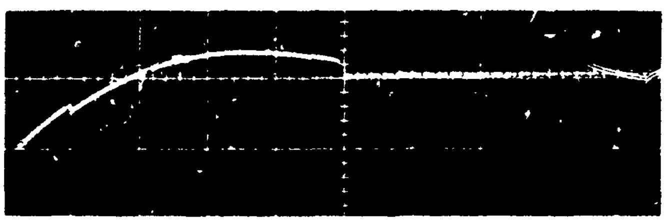


FIGURE 16

Output of $\dot{B}_T$ Coil with Current in Gaussing Loop shown in Fig. 15

Calibration:

$V = 2.0$ V/cm

Initial Voltage Peak $\cong 1.4 \times 2.0 \cong 2.8$ Volts

$t = 100\ \mu$ sec/cm

Figure 17. Steel Container

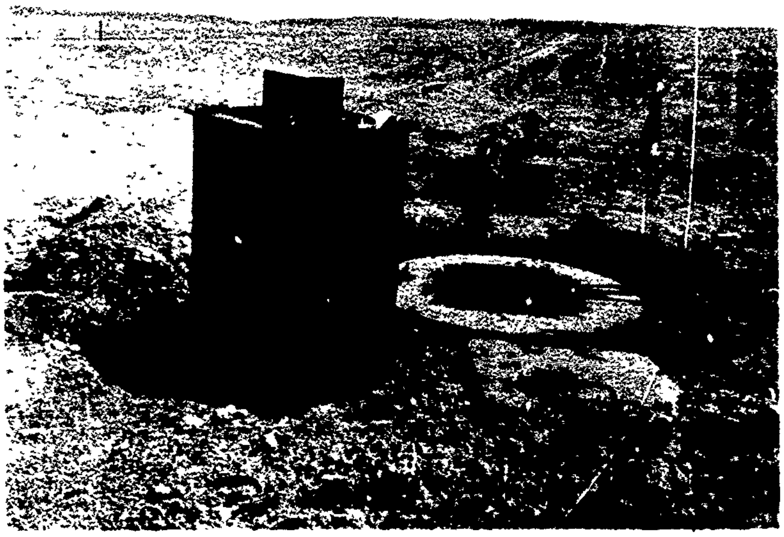


Figure 18. Buried Steel Container and Shielded Container

Figure 19. Ground Connection

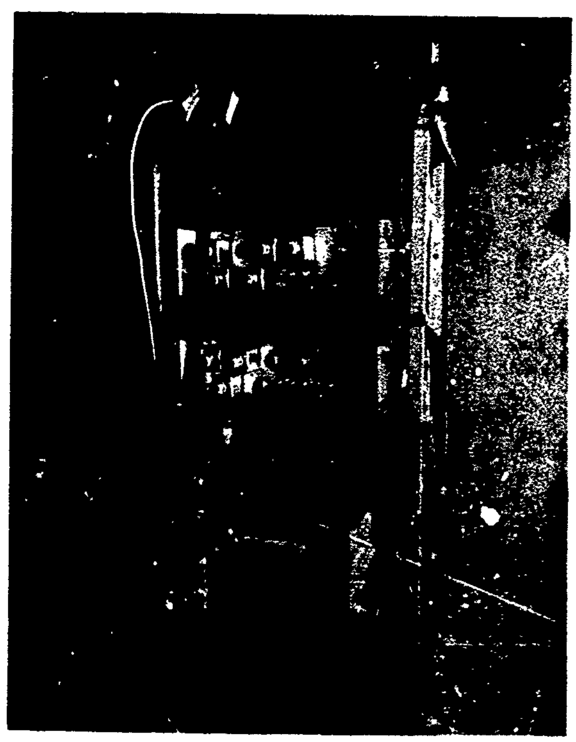


Figure 20. Instrumentation Package

Figure 21. Current Transformer Installation

Figure 23. $\dot{B}_V$ Pick-up Loop Installation

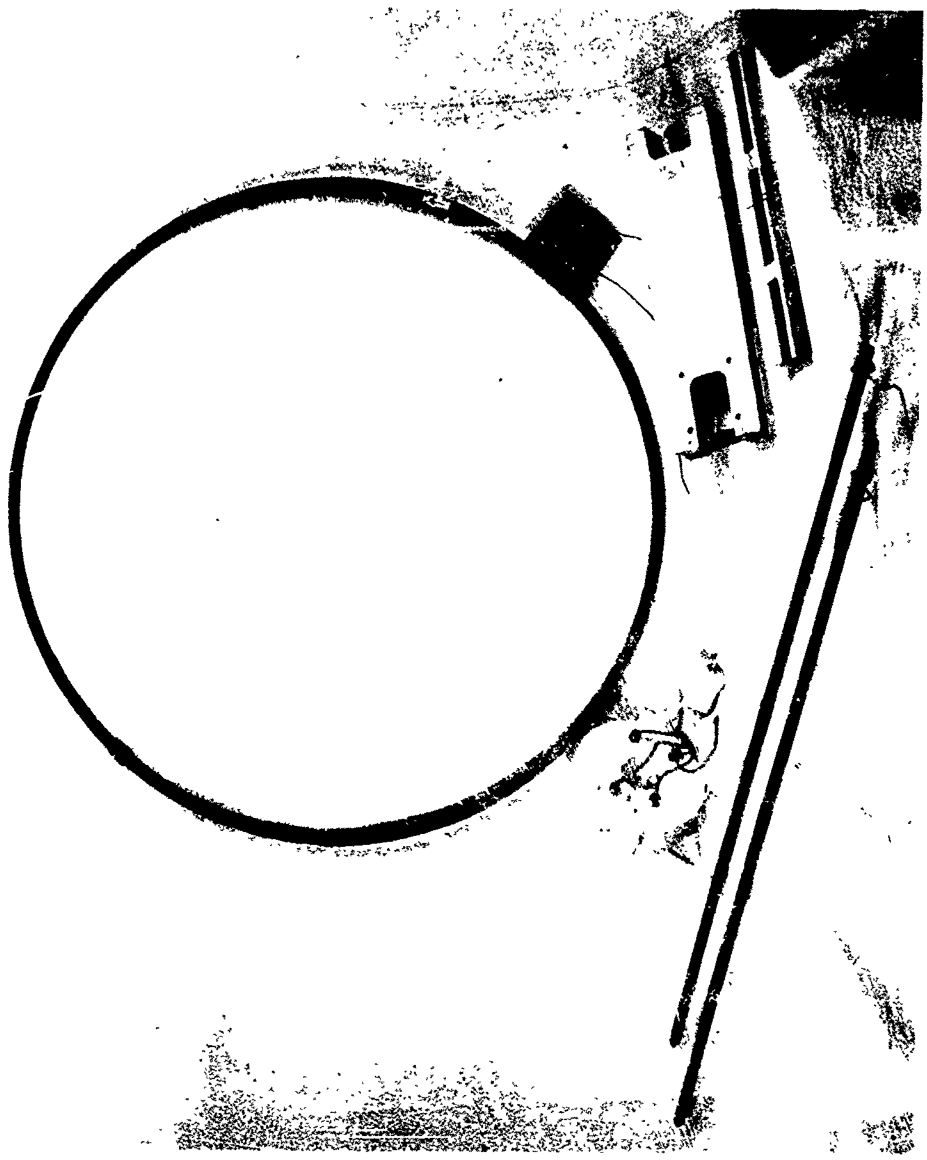


Figure 22. Sensors

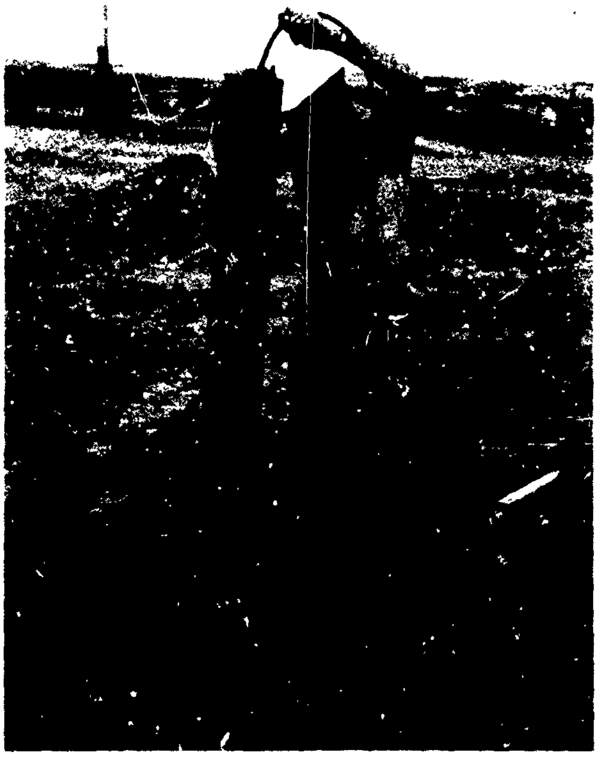


Figure 24. $\dot{B}_{V(30')}$ Pick-up Loop

Figure 25. $\dot{B}_{V(30')}$ Pick-up Loop Installation

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Figure 26. $\dot{B}_t$ Pick-up Loop Installation

Figure 27. Earth Probe Holes

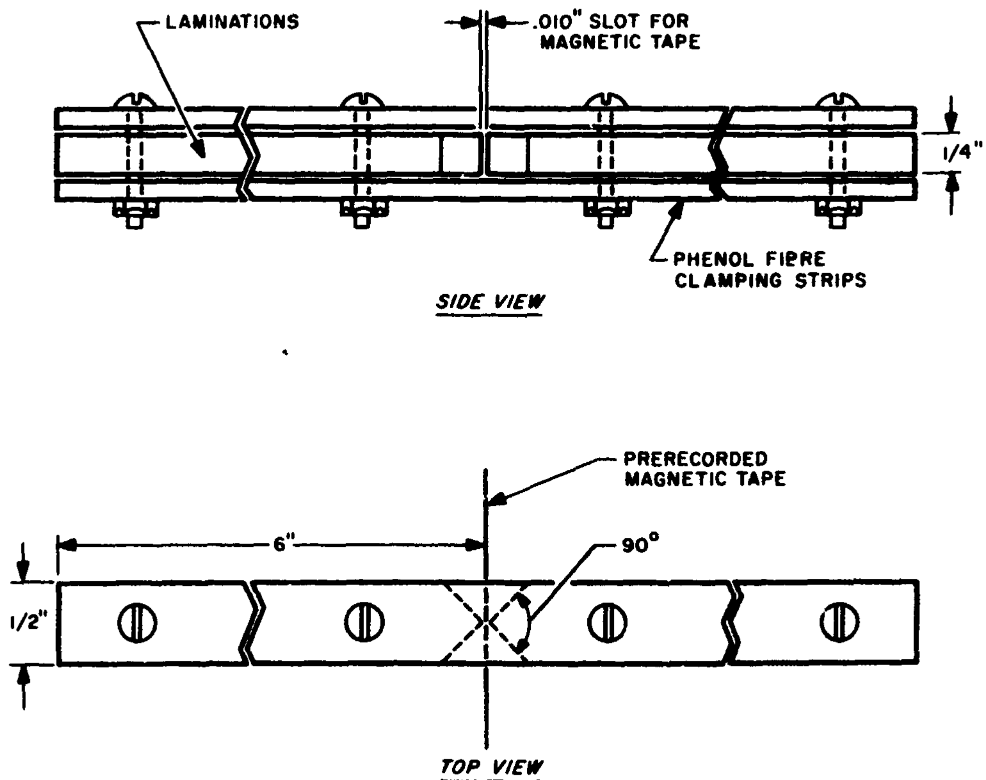


FIGURE 28. CONSTRUCTION OF MAGNETOMETER

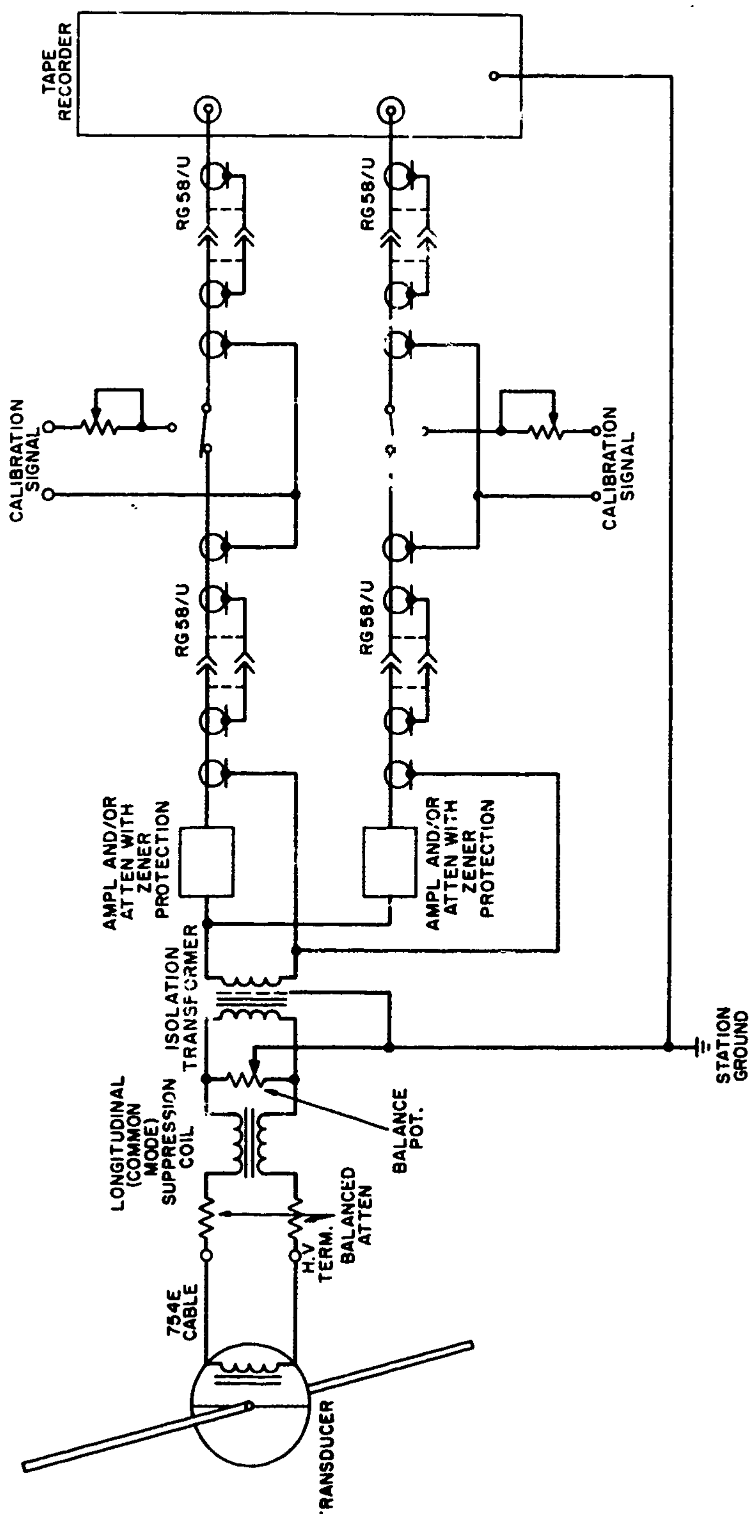


FIGURE 29 TYPICAL MEASUREMENT SCHEMATIC

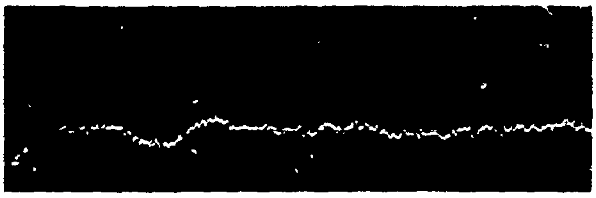


FIGURE 30

Station #1 PEMCO FM Ch 8
Signal $\dot{B}_{v(30')}$ 0.16 w/m²/s peak to peak
Vert. Sens 0.32 w/m²/s per cm
Sweep 1.0 ms per cm
Delay 50.176 ms
Filter None

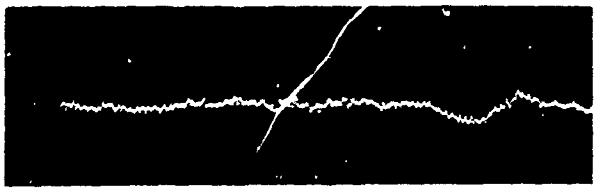


FIGURE 31

Station #1 PEMCO FM Ch 4
Signal $\dot{B}_v$ 0.0035 w/m²/s peak to peak
Vert. Sens 0.007 w/m²/s per cm
Sweep 1.0 ms per cm
Delay 45.056 ms
Filter None

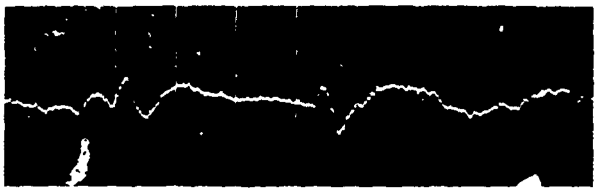


FIGURE 32

Station #1 AMPEX Direct Ch 8
Signal $\dot{B}_{v(30')}$ 0.23 w/m²/s peak to peak
Vert. Sens 0.32 w/m²/s per cm
Sweep 1.0 ms per cm
Delay 66.560 ms
Filter 300~ HP and 20 Kc LP

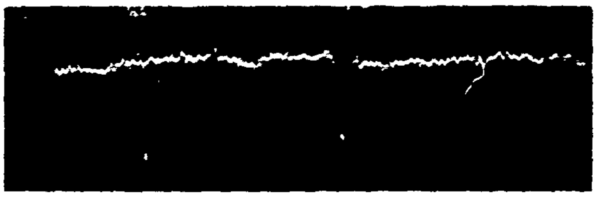


FIGURE 33

Station #1 PEMCO FM Ch 8
Signal $\dot{B}_{v(30')}$ 0.45 w/m²/s peak to peak
Vert. Sens 0.32 w/m²/s per cm
Sweep 1.0 ms per cm
Delay 66.560 ms
Filter None

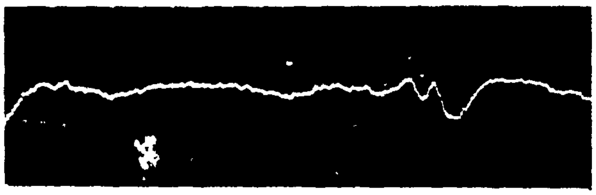


FIGURE 34

Playback AMPEX Direct Ch 8
Signal Recorder Noise
Vert. Sens 0.1 Volt per cm
Sweep 1.0 ms per cm
Delay None
Filter 300~ HP and 20 Kc LP

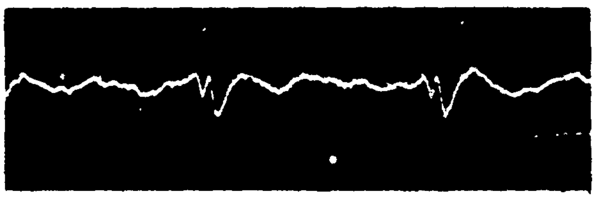


FIGURE 35

Playback AMPEX Direct Ch 8
Signal Recorder Noise
Vert. Sens 0.1 Volt per cm
Sweep 2.0 ms per cm
Delay None
Filter 300~ HP and 20 Kc LP

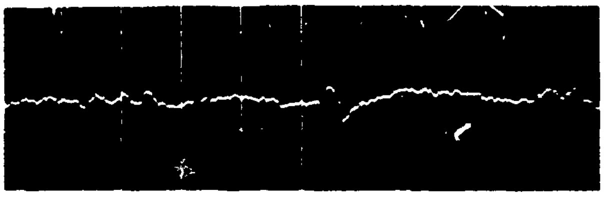


FIGURE 36

Station #1 AMPEX Direct Ch 4
Signal $\dot{B}_y$ 0.004 w/m^2/s peak to peak
Vert. Sens 0.007 w/m^2/s per cm
Sweep 1.0 ms per cm
Delay 66.560 ms
Filter 300~ HP and 20 Kc LP

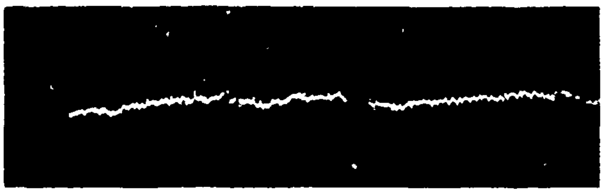


FIGURE 37

Station #1 PEMCO FM Ch 4
Signal $\dot{B}_y$ 0.008 w/m^2/s peak to peak
Vert. Sens 0.007 w/m^2/s per cm
Sweep 1.0 ms per cm
Delay 66.560 ms
Filter None

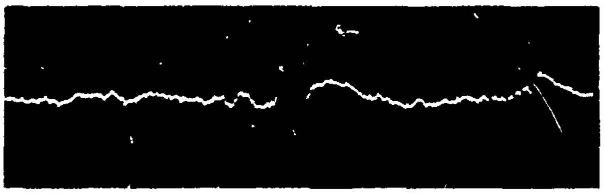


FIGURE 38

Station #1 PEMCO Direct Ch 2
Signal I_c 1.3 Amperes peak to peak
Vert. Sens 1.1 Ampere per cm
Sweep 1.0 ms per cm
Delay 66.560 ms
Filter 300~ HP and 20 Kc LP

FIGURE 39

Station #1 AMPEX FM Ch 2
Signal I_c 0.3 Ampere peak to peak
Vert. Sens 1.1 Ampere per cm
Sweep 1.0 ms per cm
Delay 66.560 ms
Filter None

FIGURE 40

Station #1 PEMCO FM Ch 3
Signal I_c 12 Amperes peak to peak (INVALID)
Vert. Sens 24 Amperes per cm
Sweep 1.0 ms per cm
Delay 66.560 ms
Filter None

FIGURE 41

Station #1 AMPEX FM Ch 10
Signal Field Mill
Vert. Sens Approx 5000 V/M per cm
Sweep 10 ms per cm
Delay 1 μ Sec
Filter None

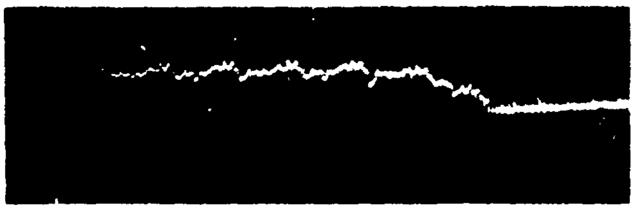


FIGURE 42

Station #1 PEMCO FM Ch 10
Signal Field Mill
Vert. Sens Approx 5000 V/M per cm
Sweep 10 ms per cm
Delay 1 μSec
Filter None

FIGURE 43

Station #3 AMPEX Direct Ch 14
Signal Zero Det.
Vert. Sens 5.0 Volts per cm
Sweep 1.0 ms per cm
Delay 1 μ Sec
Filter None

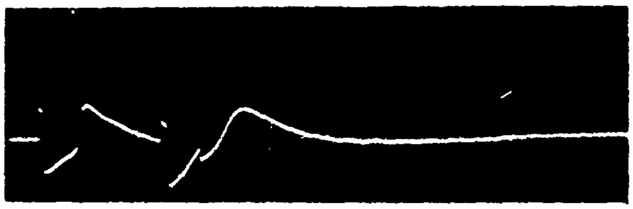


FIGURE 44

Station #3 AMPEX Direct Ch 14
Signal Zero Det.
Vert. Sens 5.0 Volts per cm
Sweep 1.0 ms per cm
Delay 74.752 ms
Filter None

FIGURE 45

Station #1 AMPEX Direct Ch 14
Signal Zero Det.
Vert. Sens 5.0 Volts per cm
Sweep 1.0 ms per cm
Delay 1 μSec
Filter None

FIGURE 46

Station #1 AMPEX Direct Ch 14
Signal Zero Det.
Vert. Sens 5.0 Volts per cm
Sweep 1.0 ms per cm
Delay 74.752 ms
Filter None

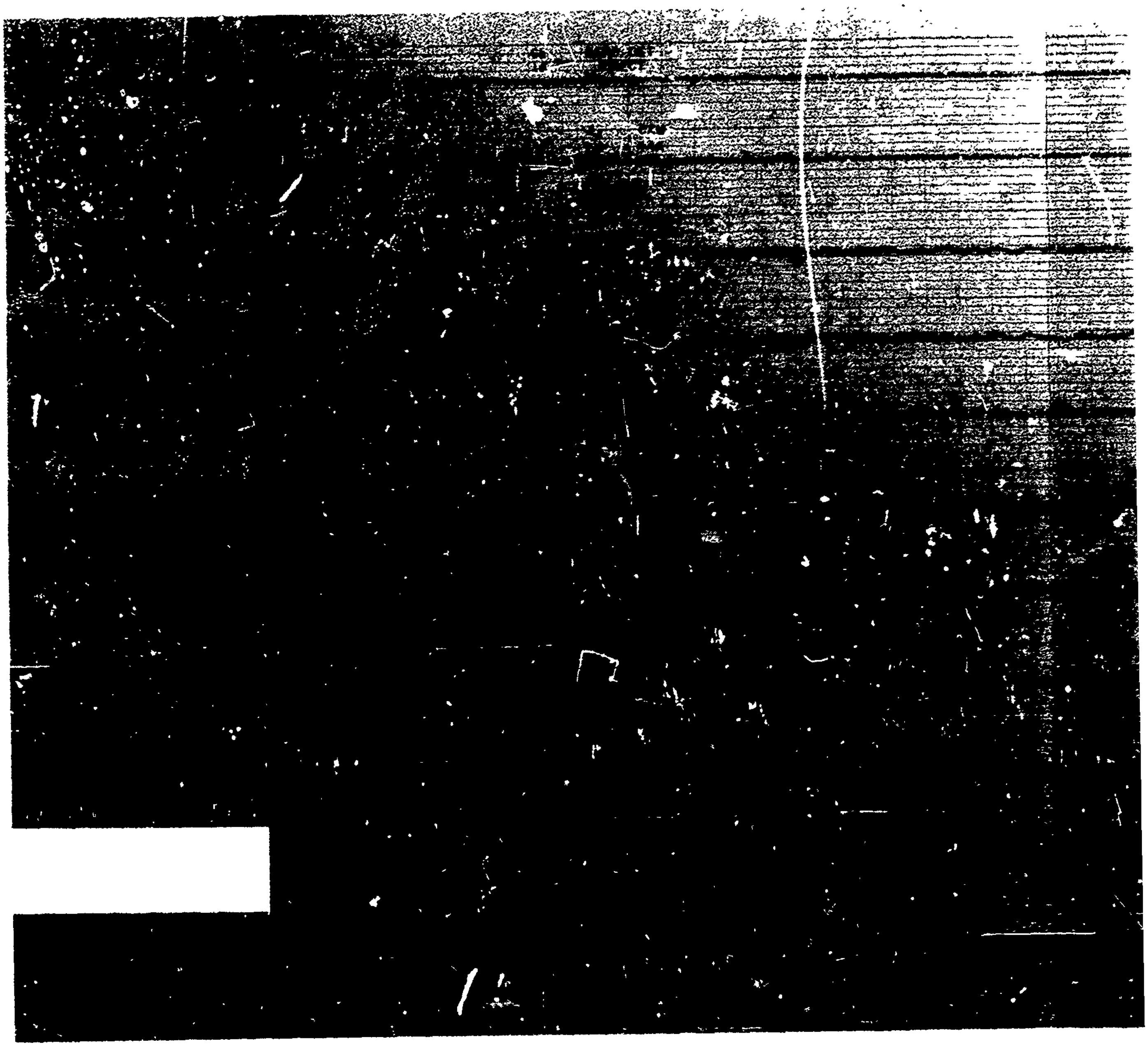


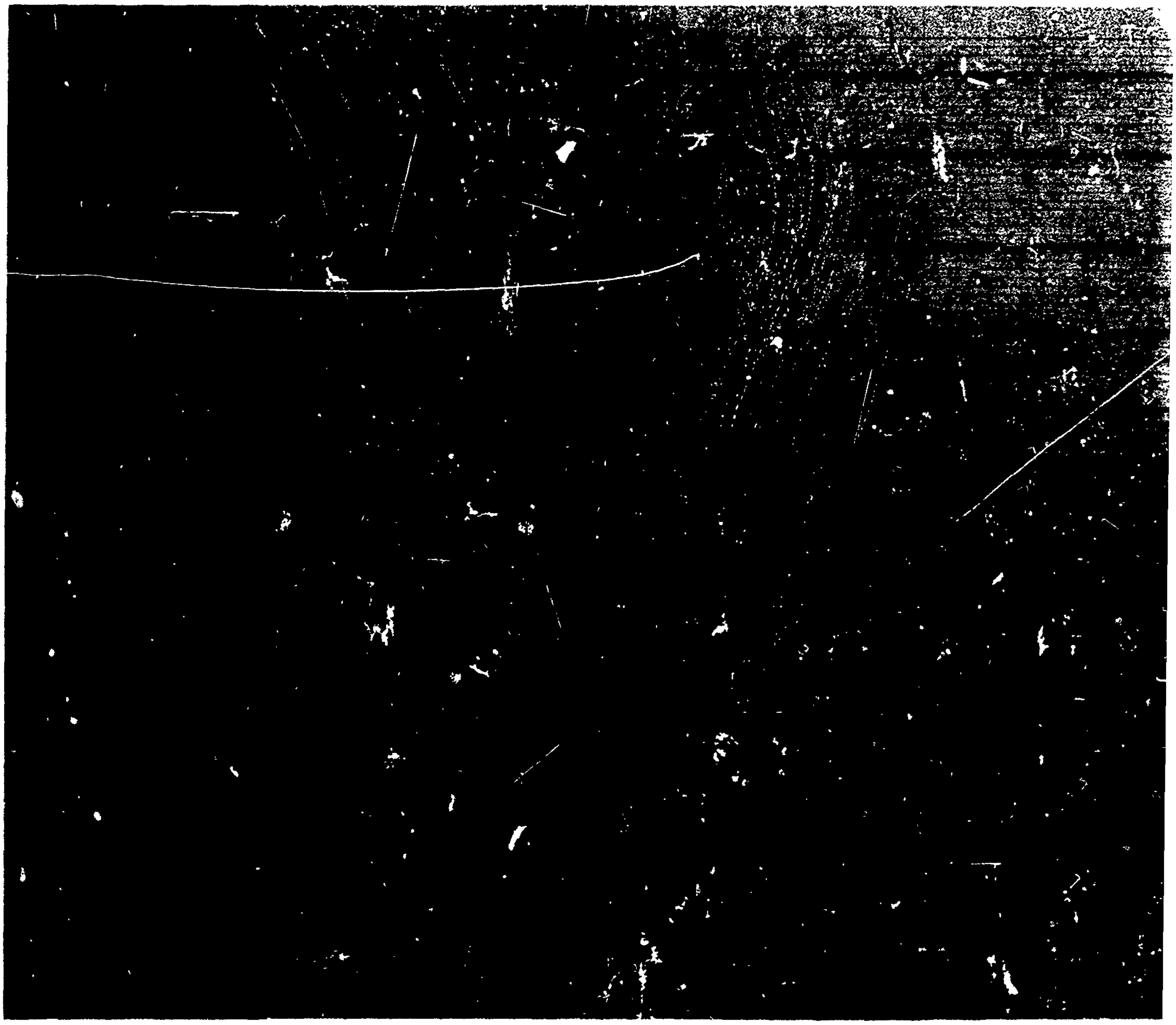
FIGURE 47 - STATION # 1

2

ION # 1

2

3



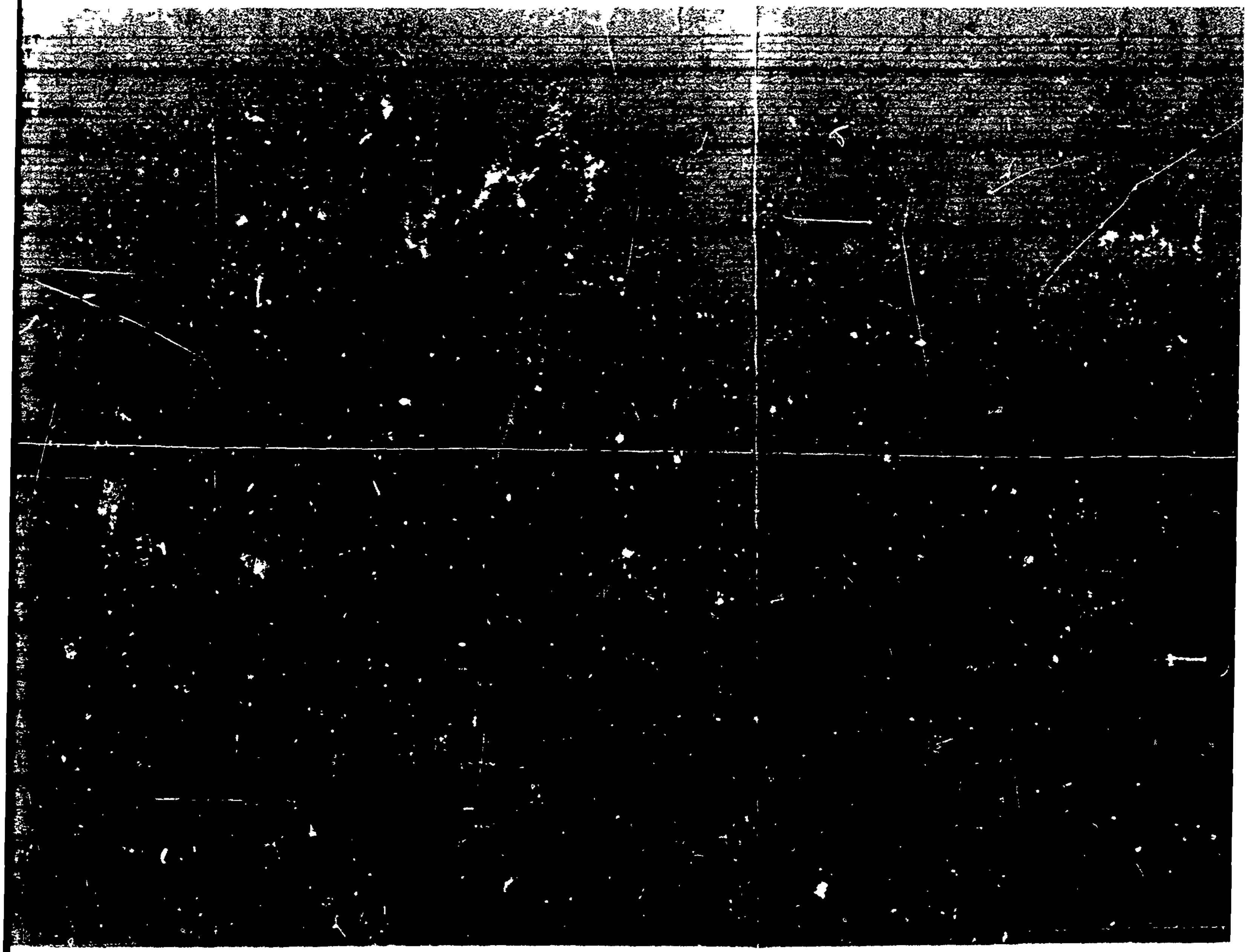
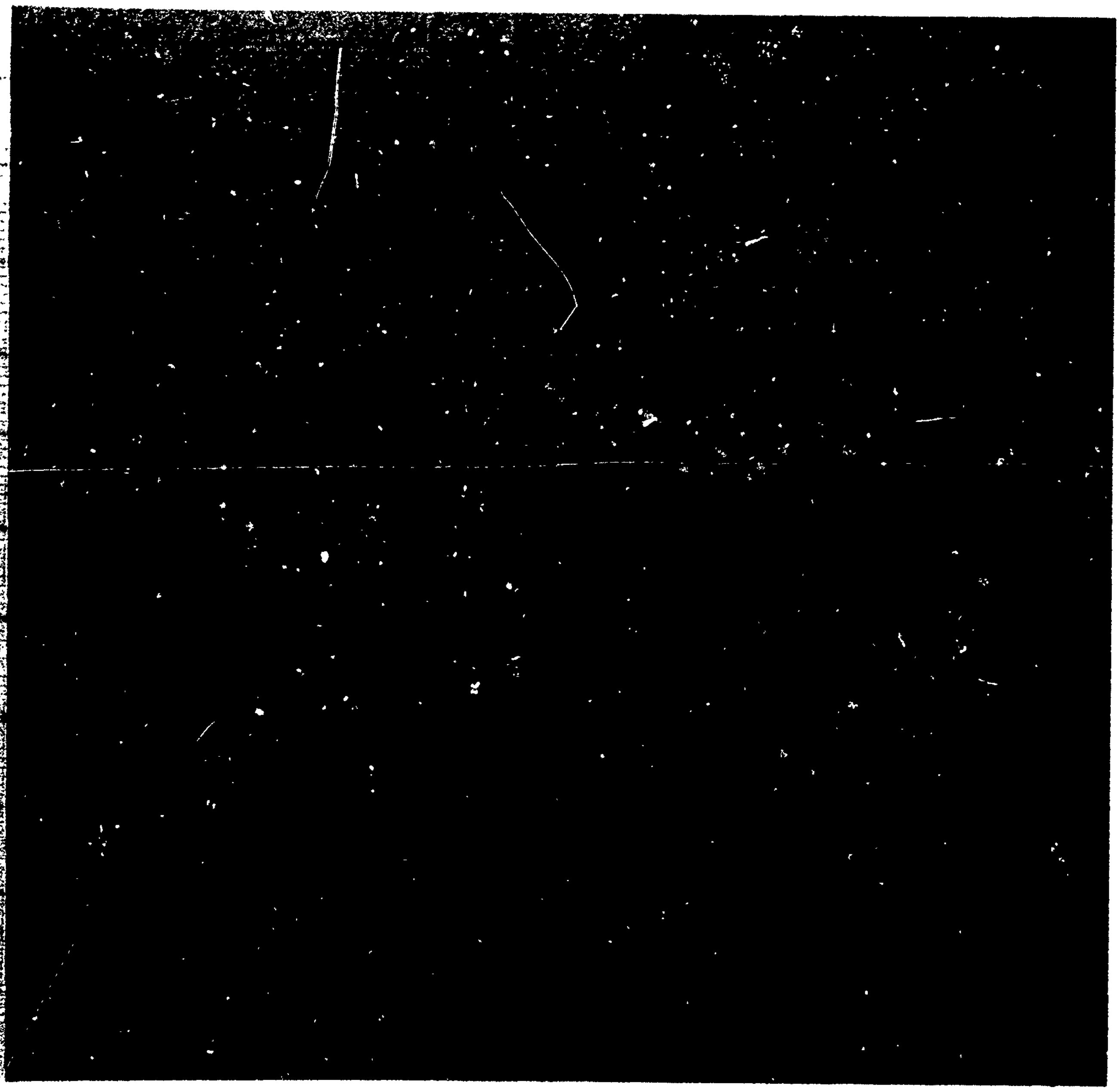


FIGURE 48-STATION #3

2



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13 ABSTRACT

This report describes an experiement conducted during the summer of 1964 at the Suffield Experimental Station, Alberta, Canada, as a part of Operation Snow Ball (a 500-ton nonnuclear explosion). The purpose of the experiment was to determine whether nonnuclear detonations may be used to investigate the Electromagnetic Pulse (EMP) phenomena. Sensors to detect electric and magnetic fields were included in Operation Snow Ball. Analysis of the data indicates that if magnetic fields were generated by the event, the fields were too small to be detected by the test instrumentation. However, the instrumentation did detect an electric field signal immediately following the detonation. The results point out the need for either increased yields or increased detector sensitivity before further participation in nonnuclear events is warranted.

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